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ABSTRACT

Intended as a general reference handbook for those concerned with applying telecommunications technology to the process of education, this survey focuses on the use of the technology rather than the technology itself. It reviews engineering or technical aspects to provide sufficient background to permit the reader to evaluate each component or system with respect to educational objectives. It also provides relevant cost and coverage data which will assist in developing the foundation for more effective application of telecommunications. In addition, the volume provides descriptions of the components and techniques used in educational telecommunications; it reviews the carrier and distribution subsystems available for transmission; it offers examples of integrated educational systems; and it forecasts trends, future applications, and projected evolutionary telecommunications networks. (Author/SH)

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A PLANNING DOCUMENT FOR THE ESTABLISHMENT OF A NATIONWIDE EDUCATIONAL TELECOMMUNICATIONS SYSTEM

TELECOMMUNICATIONS IN EDUCATION

CARL PILNICK
and
HARRY R. GLIXON

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A PRIMER ON TELECOMMUNICATIONS IN EDUCATION

Carl Pilnick

Harry R. Glixon

U.S. DEPARTMENT OF HEALTH,
EDUCATION & WELFARE
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I. INTRODUCTION

Chapter 1. Scope and Background
Chapter 2. Terms and Definitions

CHAPTER 1 - SCOPE AND BACKGROUND

1-1 Scope

This survey is intended as a primer or general reference handbook for the educator, the educational administrator and those in the government and educational communities concerned with applying telecommunications technology to the process of education.

The generally accepted definition of "telecommunications" implies (1) separation in distance between the source and reception of information, and (2) the use of electronic/electrical/electromagnetic techniques to transfer that information.

The emphasis throughout is upon use (or potential use) of the technology, not upon the technology itself. Engineering or technical aspects are reviewed necessarily to provide sufficient background to permit the reader to evaluate each component or system with respect to educational objectives.

Definition of those objectives is not within the scope of this volume. Telecommunications' role in education is considered herein as essentially providing remote information transfer. Since educational criteria (such as motivation, the learning process, etc.) are not included, optimal information transfer may bear little relation to optimal education. The latter depends more upon the content and method of presentation of the information (i.e., the "program") than upon techniques for its delivery.

If, for example, the aural and visual characteristics of a film or videotape are reproduced with adequate fidelity, then the telecommunications system is assumed to be performing its information transfer function. Obviously, if the content of the film is poor, there will be unsatisfactory performance of the educational function.

Ideally, the establishment of educational objectives (and, concurrently, of criteria and a methodology by which achieving those objectives can be measured and evaluated) should precede a review of the available technology. In that way, telecommunications components and systems can be selected which best match the objectives.

Considering the difficulty in obtaining consensus among educators in defining objectives, a less ideal, but perhaps more practicable approach to applying telecommunications is to start with a familiarity with the current technology, what equipment is available, and what applications have already taken place. From there, a knowledge of future technological trends can extend the spectrum of alternatives.

This base of technological information, when combined with educational creativity (constrained of course by ubiquitous budgetary limitations), can provide the foundation for more effective application of telecommunications. Educational objectives should still be defined before system implementation (nothing is sadder or more expensive than a technological system which outraces its social objectives), but the process can be iterative. The iterations can converge between cost-effective technology and improvements, at least, over previous educational performance.

The intent of this volume is to supply much of the basic technology information, together with relevant cost and coverage data, which will assist such iteration. Only an introduction to components and systems can be provided in many cases, so that the referenced bibliographic material should be reviewed in any specific area of interest.

Section II of this volume provides descriptions of the components and techniques used in educational telecommunications. Section III reviews the carrier and distribution sub-systems available to transmit electrical information from one point to another, with discussion of their relative costs and advantages.

Examples of *integrated educational systems* (where "integrated" refers to the inclusion of all elements of the system from the *information source* to its *point of reception and use*) are provided in Section IV.

Finally, some brief forecasts of *trends*, *future applications* and projected, evolutionary, telecommunications *networks* are provided in Section V.

1-2 Background

Figure 1-1 illustrates, in truncated form, the chronology of telecommunications applications to education, starting about the time of construction of the first educational radio broadcast station over 50 years ago.

It may be noted that, until the last decade, most applications have been of the "single-medium" type. By this is meant that only one form of educational or instructional material was made available to the student audience. This might be a radio broadcast to a large number of listeners or a foreign-language recording made available to a single student at a listening station in a school's "learning laboratory". The advent of television permitted both aural and visual material to be transmitted, but the single-medium character of the communications did not change.

The essential point is that the available technology was used to simulate, as closely as possible, the conventional teacher-student relationship and classroom environment. A television broadcast, in most cases, would parallel the classical "impartation-of-knowledge" techniques a teacher might use if the audience were physically in his classroom.

This approach is certainly valid and will continue to be used. Only in the last decade, however, has telecommunications technology begun to be utilized on a "multi-media" basis, An automated audio/visual retrieval system, for example, can provide upon request a playback of an audio tape, or a film or television program, from a large program library. Computer-based systems can provide formalized instruction and drill in specific subjects, or can be used as problem-solving tools on an unstructured basis.

Not only do these systems provide greater choice, but they also imply fundamental changes both in methods of learning and

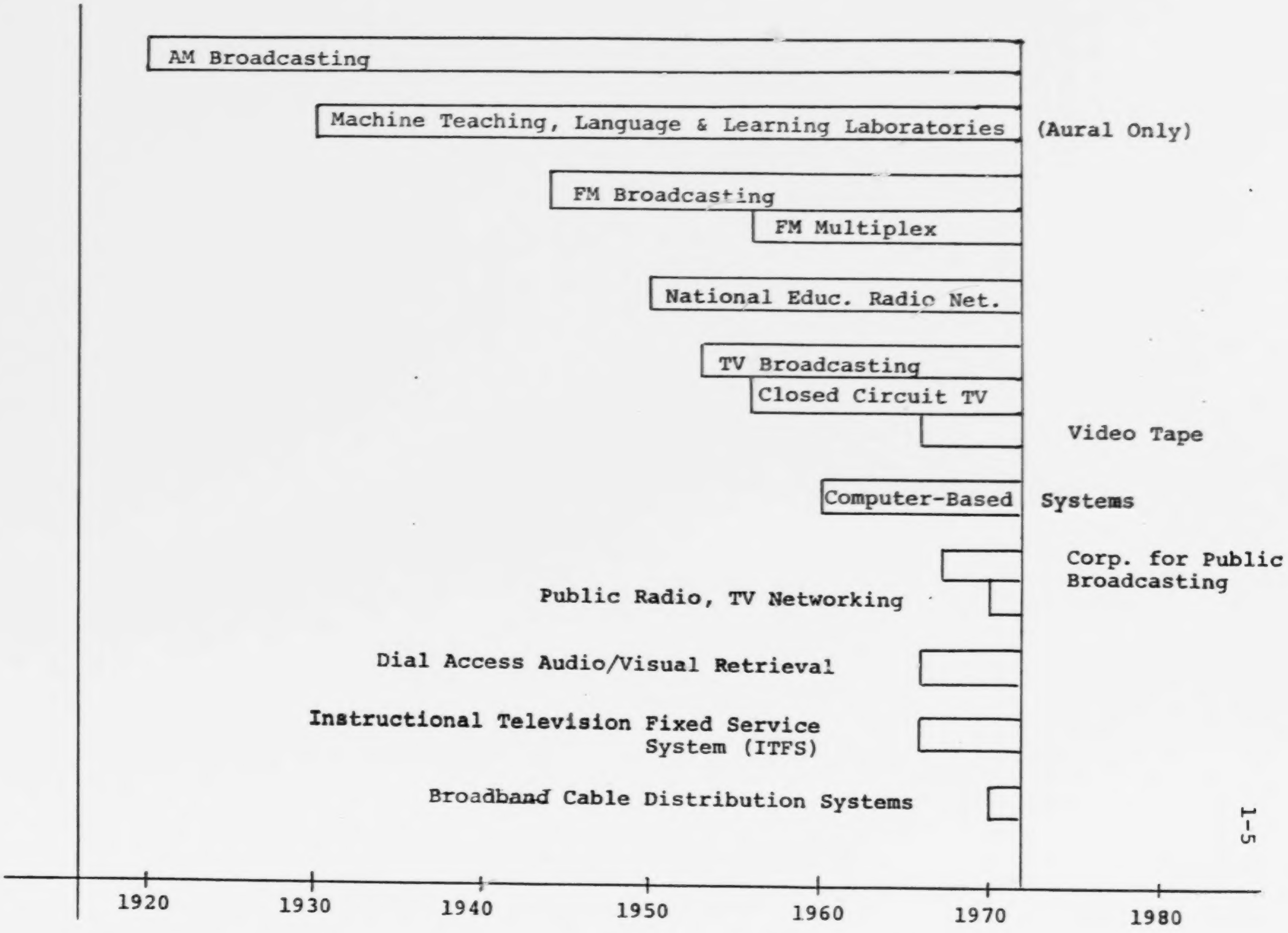


Figure 1-1 Applications of Telecommunications to Education

in the teacher-student relationship. The more sophisticated systems may be viewed as "learning resources" (as contrasted to the older concept of "teaching machines"), and to a larger extent their use will be student-directed and student-paced.

This does not mean a lessening of the teacher's role. In fact, quite the reverse is true. The teacher who is involved with such interactive systems must not only retain the basic educational skills, but also become aware of both the technology (to a limited extent) and the psychology (to a much broader extent) involved in using such systems effectively. Specialized subject knowledge will be supplemented not only by traditional teaching proficiency, but also by a newer professionalism in such areas as:

- Diagnosing the results of student-paced instruction, and prescribing appropriate support.
- Evaluating, on a comparative basis, the cost-effectiveness of telecommunications techniques.
- Providing the interface between user and system ("man and machine"), very possibly with a different degree of interfacing required by each student.
- Preparing or recommending new program material, in a form which both provides effective education and uses the technology appropriately.
- Planning to meet, through telecommunications, the requirements of a more remote, more diversified student audience than normally encountered in an on-campus environment.

Obviously, not every teacher or educational administrator will become heavily involved in advanced-technology systems, nor be required to become expert in the related gamut of knowledge. The corollary is probably true, however, in that (within perhaps 3-5 years) no teacher will remain completely untouched by some aspect of telecommunications-augmented education.

CHAPTER 1 - BIBLIOGRAPHY

1. "Computers: Super-media for education?", Computer Decisions, April 1970, p. 23-26

2. Klein, M.L. and Klein, R.L., "Progress in the Application of Technology to Education", Presented at the 1968 Western Electronic Show and Convention.

3. Martin, James, "Future Developments in Telecommunications," 1971, Prentice-Hall (Library of Congress Card No. 74-156757)

4. Martin, James,"Telecommunications and the Computer", 1969, Prentice-Hall.

5. Oettinger, A.G., "Run, Computer, Run", Harvard University Press, Cambridge, 1969.

6. Silberman, C.E., "Technology is Knocking at the Schoolhouse Door",Fortune, Aug. 1966, p. 120.

7. Skinner, B.F. "The Technology of Teaching", Appleton-Century-Crafts, N.Y., 1968.

8. Wilson, Ira G. and Marthann E., "Information, Computers, and System Design", 1965, John Wiley & Sons (Library of Congress Card No. 65-21430)

CHAPTER 2 - TERMS AND DEFINITIONS

For those with little or no experience with electrical and telecommunications fundamentals, this chapter provides a brief introduction to the terminology and elementary concepts. The treatment is necessarily superficial but should serve at least as a preliminary frame of reference from which to continue through the remaining chapters. More detailed material is available in the references cited in the Bibliography and in numerous other introductory texts.

2-1 Fundamental Electrical Terms

An understanding of some dozen or so fundamental electrical terms will provide sufficient background to proceed with the review of telecommunications systems and applications.

Probably the most difficult term of all to define is "electricity" itself, since we possess an excellent knowledge of what it can do and how to predict its behavior without really having a satisfactory description of its basic property. With respect to this volume, it will simply be considered as a form of energy which can be transmitted over distance.

"Electronics" originally referred to the use of vacuum-tube devices to control and manipulate electrical energy. Since vacuum-tubes have, in the main, given way to solid-state devices such as the transistor, electronics is now a more generalized term and usually connotes any equipment or technique used in controlling the flow-of electricity.

The transfer of electrical energy from one point to another most often occurs as one of two phenomena:

(a) the physical movement of charged molecular particles (usually electrons) through a material.

(b) the radiation of electromagnetic waves through space.

Since the second mode can occur even in a vacuum (e.g., our radio communications with the Apollo astronauts on the moon), radiated transmission is considered as a movement or variation of energy fields or waves rather than particulate motion, but this explanation, while empirically satisfactory, reveals again a limited understanding of the basic phenomena.

This limitation does not prevent our use of electricity, or the ability to design equipment which can control its effects in accordance with our desires.

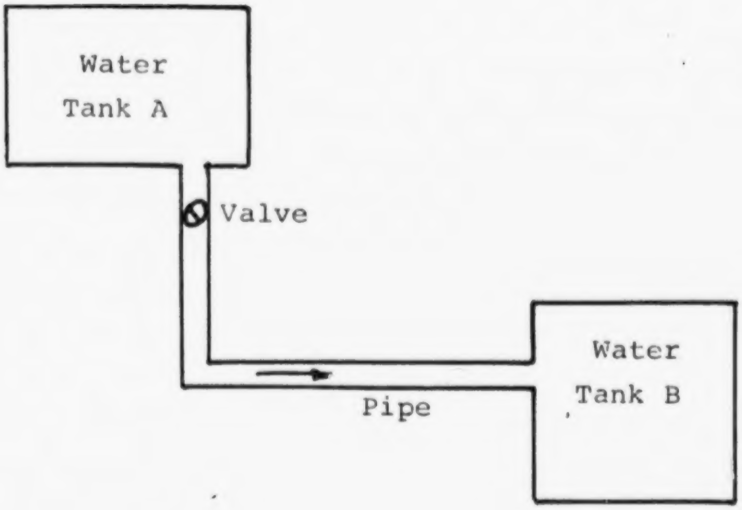
In terms of using electricity, a few parameters can define much of its behavior.

Three of the most elementary are "voltage", "current" and "resistance". Voltage (also called electric potential) is the pressure or force available to more electricity, current is a measure of the quantity of electricity moved, and resistance is the property of the medium through which the electricity moves that determines how much force will be necessary to achieve a desired current flow.

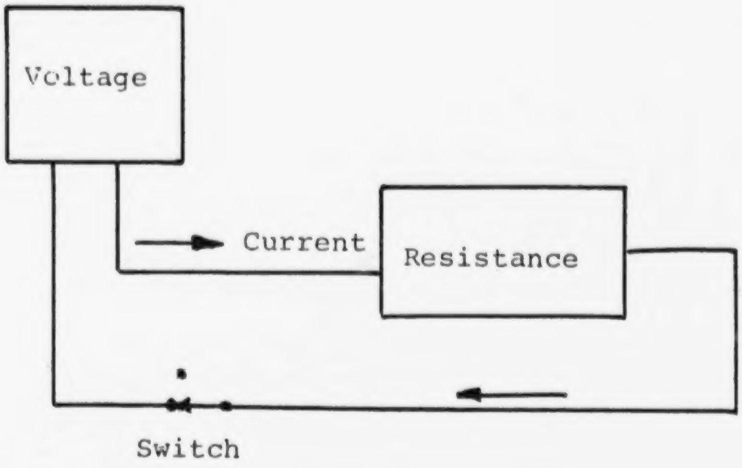
An often used analogy is shown in Figure 2-1. Water tank A is located at a height above tank B. This height difference results in a gravitational force which makes the water flow from A to B.

In an electrical circuit, the voltage is the equivalent of the gravitational force, and the current is the equivalent of the amount of water flowing per unit time. The resistance is the equivalent of the pipe diameter. If the pipe were large, the rate of flow would be greater than if it were small.

Note that if water tanks A and B were at the same height, and initially contained the same amount of water, there would be no flow. This means that the relative difference in water pressure, or gravitational force, between A and B is the determining factor and not the absolute value of either A or B alone. This is also true in electrical circuits where the


Water
Tank A
Valve
Water
Tank B
Pipe

(a) Water Flow


Voltage
Current
Resistance
Switch

(b) Current Flow

Figure 2-1

Flow of Electrical Energy

difference in electric potential, or voltage, determines current flow. Two similar batteries connected in a circuit so that their voltages oppose and cancel each other will result in no current flow.

The magnitude of the resistance to electrical flow is a physical property of the material through which the flow occurs. Metals, which make up all the wire transmission networks, have a low resistance (high conductivity) to the flow of electricity. In practical terms this means that relatively low voltages can force higher currents through metal than through most other materials.

Electrical power is a measure of both voltage and current, and indeed is defined as their product. Electrical energy is the power expended over a period of time.

In mathematical terms, the following relations hold:

(a) Voltage (volts) = Current (amperes) x Resistance (ohms)
or, symbolically: $E = I \times R$

(b) Power (watts) = Voltage (volts) x Current (amperes)
$P = E \times I$

(c) Energy (watt-hours) = Power (watts) x Time (hours)
$\text{Energy} = P \times T$

Another basic electrical concept is that of "frequency", and this term is especially important in telecommunications. Figure 2-2 shows a second analogy which can be used to understand frequency.

Tanks A and B are at the same height and initially hold the same amount of water so that normally there is no flow in either direction. Pumps 1 and 2 can be turned on or off at will. Pump 1, when on, will pump water from A to B, while Pump 2 will pump water in the reverse direction from B to A.

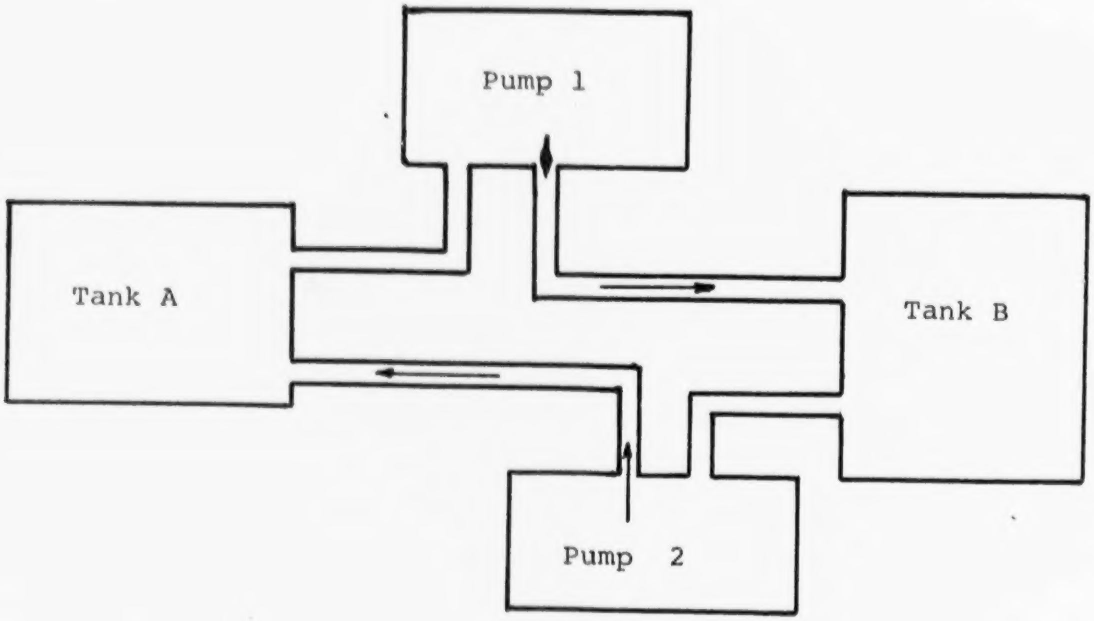

Pump 1
Tank A
Tank B
Pump 2

Figure 2-2

Analogy to Alternating - Current Flow

If only Pump 1 is turned on, water will continue to flow from A to B until tank A is empty. This uni-directional flow is equivalent, in electrical terms, to "direct current" (DC), in which the flow of electrons is always in the same direction in an electrical circuit.

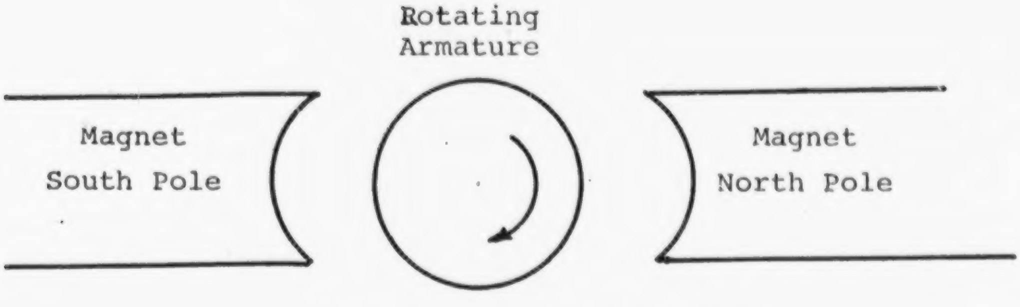
Now assume, Pump 1 is turned on for only one-half second, and then turned off. At the same time Pump 1 is turned off, Pump 2 is turned on, again for a half-second. The water would flow from tank A to B during the first half-second, and from B to A the next half-second.

Further, if this switching cycle were repeated indefinitely, the direction of water flow would alternate at the on-off rate. If a complete cycle were defined as one A-to-B flow and one B-to-A flow, then in this case the rate would be one cycle per second.

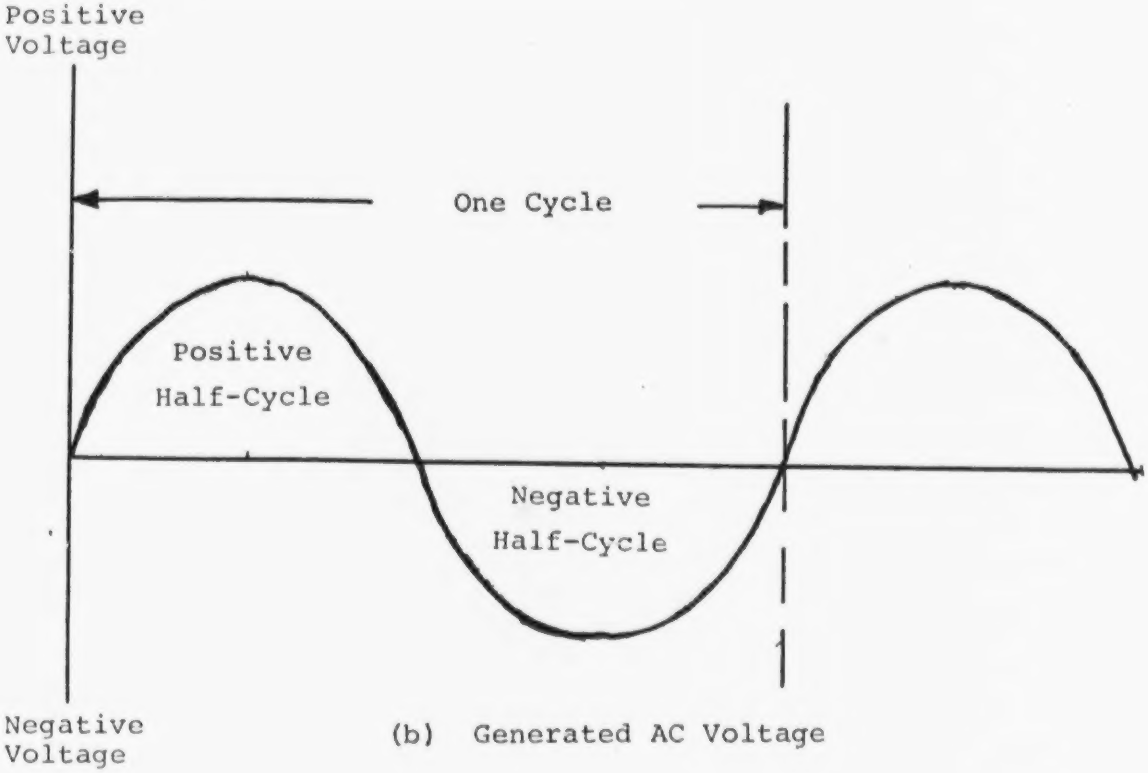
It is important to realize that, although the average water level in each tank does not change, power and energy are being expended and can be utilized. Neglecting the minor efforts of switching, it takes as much energy to keep Pumps 1 and 2 working half-time as it would to keep either pump alone working full-time. Thus, the power input in the direct flow case is the same as in the alternating flow case. If we can find a way to use the flow of water, whether direct or alternating, the energy output available would also be the same.

The alternating water flow of Fig. 2-2 is similar to "alternating current" (AC) in electricity, in which the voltage changes polarity periodically and the current flow alternates accordingly.

The machines which generate electrical power, in their simplest form, normally produce alternating voltages. Fig. 2-3 (a) conceptually illustrates a generator which consists of an armature (containing coils of wire) made to rotate in the field of a magnet. The interaction between the magnetic field and the rotation induces a voltage in the armature coils. From Fig. 2-3 (a), it can be seen that as the armature rotates it will


Rotating
Armature
Magnet
South Pole
Magnet
North Pole

(a) Electrical Generator


Positive
Voltage
One Cycle
Positive
Half-Cycle
Negative
Half-Cycle
Negative
Voltage

(b) Generated AC Voltage

Figure 2-3

Generation of Alternating Voltage

sequentially pass through areas of greatest magnetic strength and areas of little or no magnetic strength. Further, the north and south poles of the magnet will induce voltages of opposite polarity.

The resulting generated voltage is shown in Fig. 2-3 (b). It is an alternating voltage known as a "sine wave" because it can be shown that the magnitude of the voltage varies in accordance with the mathematical value of the sine of an angle.

One cycle of this AC voltage is shown, consisting of two opposite half-cycles. Each successive cycle is a repetition of the first.

The rate at which these AC cycles repeat is the frequency of the electrical voltage or current. If the generator of Fig. 2-3 (a) rotated at 60 revolutions per second (3600 rpm), the voltage it produced would have a frequency of 60 cycles per second.

If AC were produced by some other source and it was an irregular wave-shape rather than a sine wave, but still contained current reversals, it can be shown mathematically that it can be broken down into the sum of a number of pure sine waves and treated therefore as a composite of those frequencies. Thus, any alternating electrical flow, regardless of its pattern, can be considered through its separate components.

The difference, in cycles per second, between the lowest and the highest frequency components of the composite AC voltage is defined as the "bandwidth". For example, if an AC composite voltage was made up of a 40 cycle per second sine wave, a 100 cycle per second sine wave, and a 500 cycle per second sine wave, the bandwidth would be 500-40, or 460 cycles per second.

(In recent years, the term "Hertz" (abbreviated Hz) has been adopted internationally as a replacement for "cycles per second", and therefore it will be used from this point on. Table 8-1 lists the various prefixes associated with Hertz and their respective values.)

Value	Term
1 Hertz =	1 Hz (formerly 1 Cps)
1,000 Hertz =	1 Kilo Hertz (1 KHz)
1,000,000 Hertz =	1 Mega Hertz (1 MHz)
1,000,000,000 Hertz =	1 Giga Hertz (1 GHz)

Table 8-1

Frequency Equivalents

Bandwidth is an important concept with respect to telecommunications, since it is a measure of how much information can be accommodated. Later discussion will expand its specific meaning and application.

DC plays a relatively unimportant role in telecommunications. AC can be transformed (changed in magnitude of voltage and current) and amplified much more easily than DC, and this permits easier matching to a variety of electronic devices which make up the telecommunications system. Even when a source of electrical energy (e.g., a battery) produces DC directly, it must be converted to AC to radiate it from a transmitter, for example.

With the foregoing review of basic electrical terms, the process of transferring information via electricity can be discussed.

2-2 Information Transfer and Bandwidth Concepts

Figure 2-4 illustrates, in simplified form, the elements of a telecommunications system.

In most educational applications, the source information is aural and/or visual in character. Information transfer via senses other than the eye and ear (i.e., smell, touch, taste) is sufficiently rare (and incompatible with telecommunications) to be neglected here.

The function of the telecommunications system is to convert this aural/visual information into electrical form at the source, transmit it to the receiving location and there reconvert it, as faithfully as possible, to the original.

Aural information, in electrical form, is called "audio", and correspondingly "video" is the term corresponding to the electrical form of visual information (which leaves the commonly used phrase "audio/visual" in no-man's land).

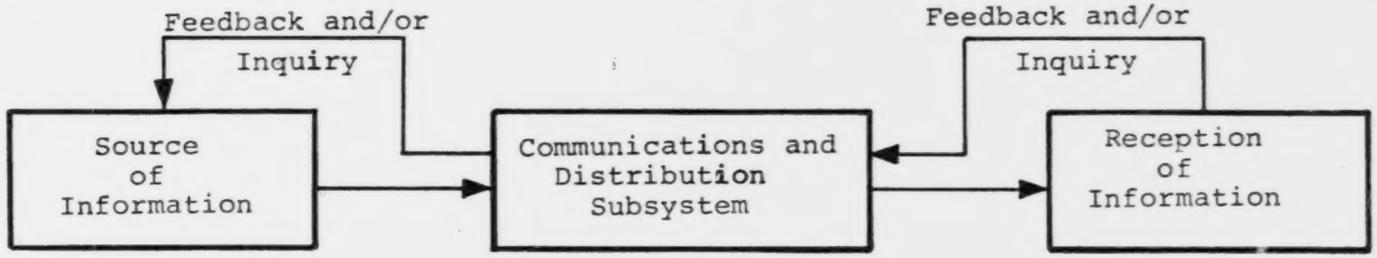

Feedback and/or
Inquiry
Feedback and/or
Inquiry
Source
of
Information
Communications and
Distribution
Subsystem
Reception
of
Information

Figure 2-4

Basic Telecommunications System

Sound waves, or aural information, are absorbed through the human ear as energy transmitted through air in the form of a traveling fluctuation in air pressure. Sound is usually measured in terms of two parameters, "intensity" (loudness) and "frequency" (pitch), which also have their electrical equivalents in "amplitude" and "frequency" respectively.

The frequency range for human hearing is about 20-20,000 cycles per second of sound energy. In terms of sound energy, the sound produced by a tuning-fork would be a single frequency, say at 1,000 cycles per second. The sound of human speech or music would be a composite of many single frequencies, much the same as the AC composite electrical signal mentioned previously.

Because of the similarities, sound energy can be transformed into electrical form almost on a "one-for-one" basis, i.e., the 20-20,000 cycle per second bandwidth of sound energy converted into an equivalent 20-20,000 Hz electrical bandwidth.

An ideal communications system transmitting only aural information would convert and transmit the original sounds without loss or distortion. This is equivalent to the performance of a high-quality stereo set (e.g., "flat response" from 20-20,000 Hz).

In practice, however, most audio communications links operate on a much narrower frequency spectrum. The telephone line, designed primarily for voice transmission, operates, for example, on a channel only about 3,000 Hz wide. FM radio stations broadcasting so-called "high fidelity" music transmit a wider band of frequencies, but some cutoff of frequency extremes still takes place, either at the source or the receiver.

Visual information is much more complex than aural, involving motion of the visual image in time and space, as well as the process by which the human eye assembles bits of the image together into a totality. A detailed discussion of conversion of visual information is provided in Chapter 4, but at this point it can be noted that to convert a moving electrical image into electrical form, so that it can be communicated and viewed without any time delay, requires an electrical bandwidth of several MHz, as contrasted to the 20 KHz of high-fidelity music or the 3 KHz of a telephone line. Standard TV channels, for example, are 6 MHz wide, which is 2,000 times the bandwidth of a telephone line.

In any telecommunications system, the parameter of bandwidth, as related to cost, becomes the single most important evaluation criterion. For equal cost, a wider band system will permit greater information transfer per unit of time, which can either be a quantitative or qualitative (e.g., improved TV picture quality) advantage. This is why a cost/bandwidth figure of merit is used to compare telecommunications systems.

Obviously, the corollary of the previous statement is also true, i.e., that wider bandwidth costs more money. The tradeoff between cost and how fast information is to be transferred is a major decision for each system.

Wider bandwidth also permits greater flexibility. A communications link, for example, with a bandwidth of 12 MHz can carry two TV channels, or one TV channel and 1000-2000 voice-grade telephone channels, or any other combination of information messages which does not exceed the 12 MHz total capacity. A narrow-band system, on the other hand, can carry high quantities of information only by transmitting over long, "stretched-out" intervals of time, (similar to forcing a river of water through a narrow pipe). This may be tolerable for some applications (e.g., facsimile), but completely unacceptable where real-time reception is necessary, as in TV.

II. COMPONENTS AND TECHNIQUES

Chapter 3 Audio
Chapter 4 Video
Chapter 5 Hard Copy
Chapter 6 Computers

CHAPTER 3 - AUDIO

The conversion of sound into electrical form is one of the oldest applications of telecommunications, beginning with the invention of the telephone.

There are generally three reasons to transform sound energy:

(1) to reproduce the sound at the same location, but with controllable volume (e.g., public address systems)
(2) to store the sound for later reproduction
(3) to reproduce the sound at a different location

Of these, only the third falls directly within the definition of telecommunications, although the second is useful in many educational applications.

Fig 3-1 illustrates the functional components of a telecommunications system which transmits only audio information.

Since Section III deals with the methods of transmitting and distributing electrical information, including sound and pictures, this chapter focuses upon the components and techniques used at the information source and receiving points, either to convert or store sound energy, and to condition the electrical signals properly.

3-1 Sound-to-Electrical Conversion: The Microphone

Aural-to-electrical conversion is usually performed by a microphone which changes ambient sound waves into a proportionally varying electrical parameter. Either the sound pressure or the pressure-gradient (velocity) may be used.

A typical pressure-operated microphone, for example, utilizes the sound pressure to deflect a sensitive diaphragm, producing mechanical motion. This motion may change the

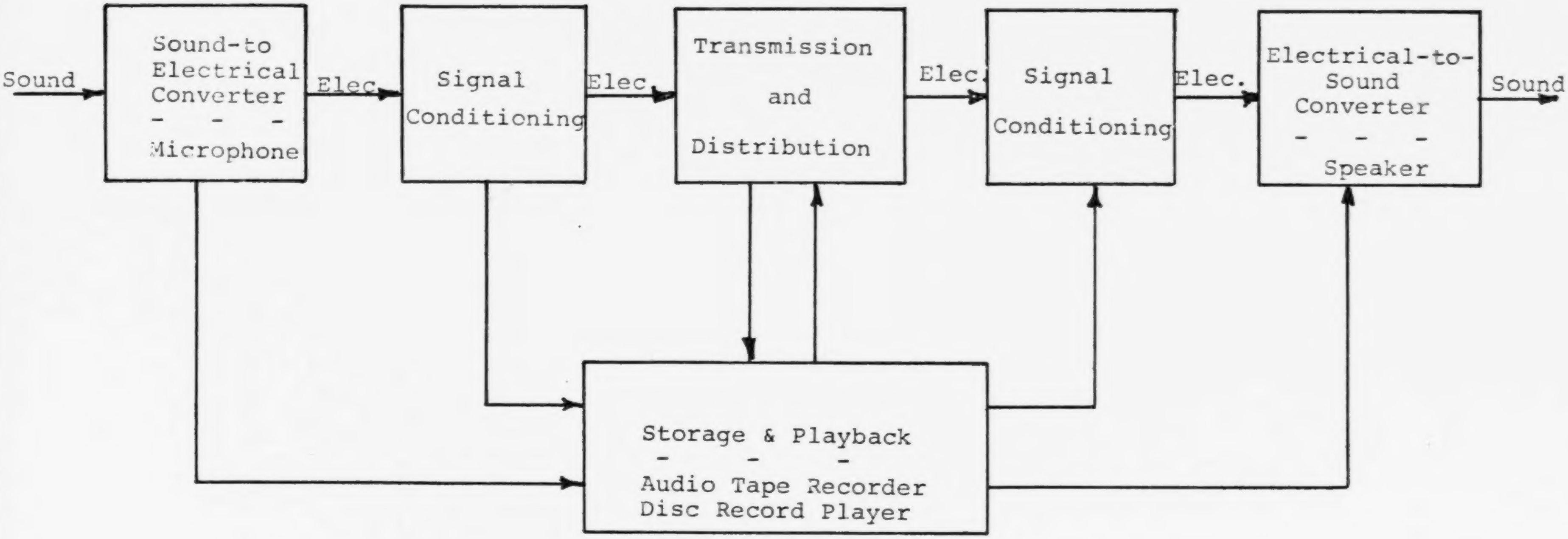

Sound
Sound-to Electrical Converter
- - -
Microphone
Elec.
Signal Conditioning
Elec.
Transmission and Distribution
Elec.
Signal Conditioning
Elec.
Electrical-to-Sound Converter
- - -
Speaker
Sound
Storage & Playback
- - -
Audio Tape Recorder
Disc Record Player

Figure 3-1

Audio Telecommunications

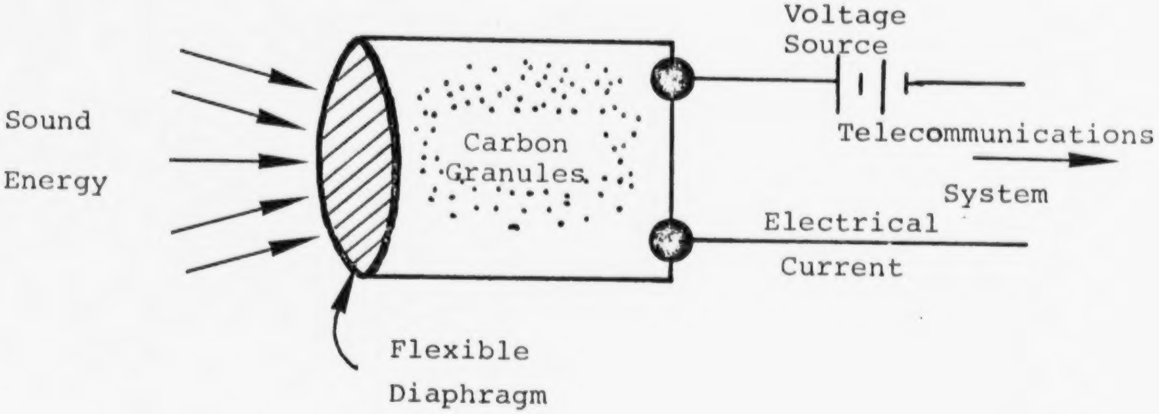
packing density of carbon granules within a small chamber, and thus change the electrical resistance of the carbon, (Fig. 3-2) or it may slightly deform a crystal which, through the piezo-electric effect, changes its capacitive reactance. In either case, the change in electrical value follows (becomes an analog of) the varying sound pressure.

The electrical output signal from the microphone, though a close representation of the sound, is low in power and in almost all cases must be amplified to be of use in transmission or reproduction. Further, the frequency range, from 20 to perhaps 20,000 Hz, is in many cases not the most efficient for long-range transmission, so that modulation (use of the information signal to control another electrical signal which serves as a carrier) is also required.

3-2 Electrical-to-Sound Conversion: The Speaker

At the receiving location, the electrical signal is converted back into a sound pattern duplicating that at the source. This accomplished by means of an electro-acoustic converter called a loudspeaker, or more simply, a speaker. In the most common version, the electrical current energizes a "voice coil" which is mounted in a magnetic field. The interaction of the quiescent field and the dynamic one produced by the currents in the voice coil will force the voice coil to move. Since the voice coil is fastened to a specially shaped flexible mechanical cone, the cone will move also, and its motion energizes the surrounding air, producing sound waves.

Speakers vary in size from the very small hearing-aid and transistor radio types or the headphones used in telephone receivers, to the large, high-power public address units designed for area coverage. They also vary in fidelity of sound reproduction from poor to excellent. The high-fidelity systems generally utilize combinations of speakers, each


Voltage
Source
Sound
Energy
Carbon
Granules
Telecommunications
System
Electrical
Current
Flexible
Diaphragm

(1) Sound Energy deflects diaphram
(2) Movement of diaphragm changes packing density of carbon granules
(3) Electrical Resistance change of carbon changes magnitude of current as an analog of the sound energy
(4) Current change is transmitted to System

Figure 3-2

Operating Principle - Carbon Microphone

reproducing a portion of the sound spectrum. Thus, "woofers" are speakers designed for the low (bass) sound frequencies, while "tweeters" reproduce the higher (treble) portion of the range.

3-3 Audio Storage and Playback

At present, audio information is most commonly stored on, and played back from, one of two media:

(1) phonograph discs
(2) magnetic tape

The wide use of both media for entertainment and education requires no elaboration. Music, drama, speeches, educational and training courses are available, both on disc and tape, in such profusion as to offer a bewildering variety of choice.

3-3.1 Disc Record Player

The phonograph, oldest of the audio storage and playback devices, has the advantage of low cost for the player and discs. A player adequate for a single classroom, where high fidelity reproduction is not required, would cost \$25-75. Long-playing (33-1/3 rpm) discs average \$2-10 each, depending upon the program material.

Apart from disc wear, which degrades playback quality with continued usage, the major disadvantage of the phonograph is that it is a playback device only, with no facility for local recording of programs. This limits educational applications to that previously recorded material which happens to be available and also fits local educational needs. Innovative program material, or material which is of interest to relatively small groups, is likely to be rare.

3-3.2 Magnetic Tape Recorder/Player

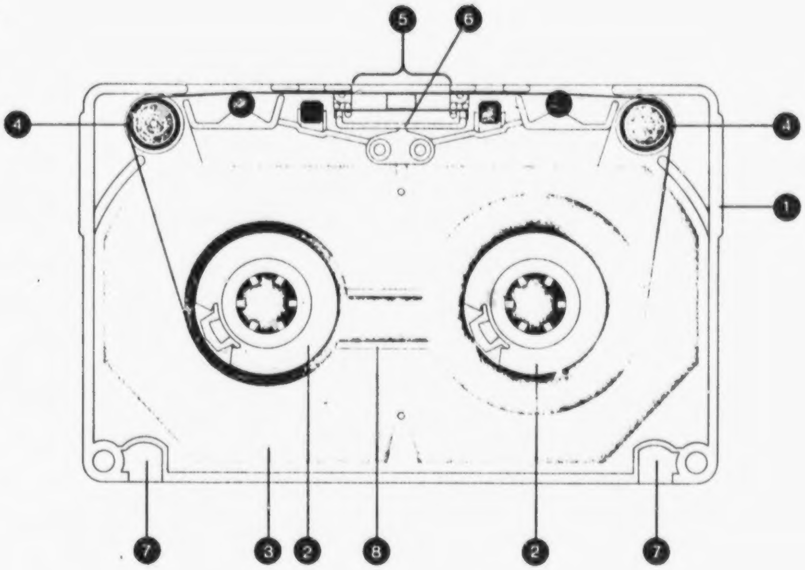
The magnetic tape recorder/player offers the advantage of convenient local recording capability, which the phonograph lacks. With a microphone accessory, any sounds capable of being heard can be recorded and stored on tape for later playback. Thus, classroom lectures, field interviews or radio or television programs can be taped for subsequent use.

Information is stored on magnetic tape by orienting the magnetic particles which coat the tape into a pattern which follows the sound variations. The electrical current output from the microphone (or any similar source) is amplified and connected to a magnetic recording "head", which generates a strong magnetic field in the vicinity of the tape moving under it. This fluctuating magnetic field moves the metal oxide particles on the tape in a manner similar to the a way a permanent magnet moves iron filings on a sheet of paper. The resulting pattern on the tape is an electromagnetically-stored equivalent of the original sounds.

For playback, the process is reversed. The prerecorded tape is moved under a "pickup" head which, in this case, senses the pattern variations of the tape's magnetic field and produces a current following the pattern. This current is amplified and used to energize a speaker, reproducing the original sound.

Until the last few years, magnetic tape was wound on open reels which required some care in handling, threading and storage. Recently, however, the introduction of the tape cassette and cartridge have greatly simplified recorder operation and provided a more convenient program module.

A cassette is basically an enclosed version of the original reel-to-reel concept (see Fig. 3-3). The two reels are enclosed in a plastic case with an opening for the



1. Cassette Case
2. Tape Supply and Take-up Reels
3. Cassette Liner
4. Tape Guides
5. Opening for Magnetic Head
6. Magnetic Shield
7. Safety Tabs (prevent accidental erasure)
8. Viewing Windows

Figure 3-3

Magnetic Tape Cassette

recorder's magnetic head. In use, the tape reels are driven so that the tape unwinds from one reel and winds onto the other. The user does not have to touch the tape itself or open the cassette.

An accepted standard at present is the "Philips" cassette, developed by North American Philips, which utilizes 1/4-inch wide magnetic tape moving at 1-7/8-inch per second rate.

A magnetic tape cartridge is a single-reel module. The tape unwinds from the reel and is designed to rewind over the same reel so that an "endless loop" is formed. Thus, if the cartridge contains music, it is possible to plug it into the player and hear the sound start in the middle of the musical piece, continue to the end, and then begin over again. This feature is useful for unattended applications, such as the music track in an airplane's entertainment system, or background music systems like Muzak.

At present, 4-track and 8-track cartridges are available, providing a range of program lengths up to several hours. As in the cassette, the user never handles the tape directly, and the cartridge is a plug-in, snap-out module.

Cassette and cartridge recorder/players are rapidly becoming competitive in price with phonograph players, ranging from $50-400 for home or classroom units, up to $500-1,000 for professional and institutional equipment. Add-on units, which physically accept the cassette or cartridge, but which use the amplifier-speaker combination of a separate stereo or radio set, are also available at a $25-100 cost range.

3-4 Signal Conditioning

3-4.1 Conditioning Requirements

Depending upon the nature of the telecommunication system, it usually is necessary to "condition" the audio electrical signals prior to transmission and distribution.

This conditioning may be required to match various items of equipment, or to achieve the most efficient form for communications.

Some of the more common requirements for electronic signal conditioning include:

(1) Amplification - used to boost the voltage and/or current levels of the signals. Since devices such as microphones and phonograph pickups produce low-power signals, and since power losses occur in almost all parts of the telecommunications system, amplifiers are an almost-universal component.

(2) Filtering - the blocking of unwanted signals while permitting the desired signals to pass through the system.

(3) Conversion - changing the form of the electrical signal to match the communications equipment. Types of conversion may include analog-to-digital (and vice versa), frequency shifting, and special coding.

(4) Modulation - combining the information signal with a transmission carrier in such a way that efficient transmission is achieved, and the information can be separated readily at the receiving end.

While the educator interested in applying telecommunications to an audio system need not have a detailed knowledge of technical aspects of signal conditioning, some familiarity is helpful in estimating total system cost and complexity.

For example, an audio system designed to broadcast to pupils assembled in a large auditorium obviously requires higher power than if the same program were sent to only one pair of headphones at a student's learning carrel. An amplifying unit for the former might easily cost several thousand dollars, while the latter would be in the $10-50 range.

Similarly, if many signals are distributed simultaneously through the same system, the filtering and conversion equipment necessary to insure that they do not interfere with or distort each other can be quite expensive. If, further, the signals are broadcast over the air waves, the FCC imposes stringent regulations on the characteristics of the signals to prevent interference with other broadcast stations. Such regulation increases the magnitude and cost of the conditioning equipment to the point where, in many systems, these costs may be the dominant factor.

3-4.2 Modulation Techniques

If aural information is converted into electrical form and transmitted to the receiving point with no significant changes other than amplification, the signals are termed "unmodulated" or " direct audio". An example would be a public address system.

While permitting the simplest equipment configuration, direct transmission of audio signals in the 20-20 KHz frequency range is inefficient either for wireless broadcasting or for wired systems exceeding a few miles. Too much power is lost during transmission, and the equipment required is excessively large and bulky. (This is related to the "wavelength" of the electrical signals, which is the inverse of frequency. Thus, low-frequency audio signals have long wavelengths).

For any long-distance applications, therefore, modulation is required. In this process, a carrier is selected which does permit efficient transmission, and the audio signals are use to modulate (vary or control) a characteristic of the carrier in such a way that the desired information content is transmitted as part of the carrier.

The two most commonly used modulation techniques for audio transmission are Amplitude Modulation (AM) and Frequency Modulation (FM). The terms, at least, are familiar to all due to their use in radio broadcasting.

3-4.2.1 Amplitude Modulation (AM)

Just as sound energy is characterized and measured through the parameters of intensity and pitch which define, respectively, the loudness and frequency, so is the audio electrical signal defined by two similar parameters, amplitude and frequency. The amplitude is a measure of the magnitude or intensity of the audio voltage or current while the frequency describes the rate of change of directional flow of current.

Figure 3-4 is a pictorial illustration of a constant-amplitude, constant-frequency "alternating current" (AC) signal, termed a sine wave. It is the form of signal produced by a rotating electrical generator, due to the physical design and location of magnet and armature. Since this kind of generator produces most of the worlds' electrical power, the AC sine wave has been adopted as the universal standard of a "raw", unmodulated (informationless) electrical signal. ("Direct current" or DC signals are used for specialized applications, but relatively rarely in telecommunications. Transmission efficiency is poor, and they present difficulty in transformation).

In Fig. 3-4, although the electrical voltage and current vary, they do so in a predetermined pattern, with each cycle being a repetitive duplicate of the others. Thus, the maximum amplitude (or any selected average or root-mean-square amplitude) can be said to be constant over any number of cycles.

If another electrical signal is added to that of Fig. 3-4, so that the amplitude of the sine wave varies in proportion to the new signal, the process is termed Amplitude Modulation The original sine wave is the carrier, and the second signal

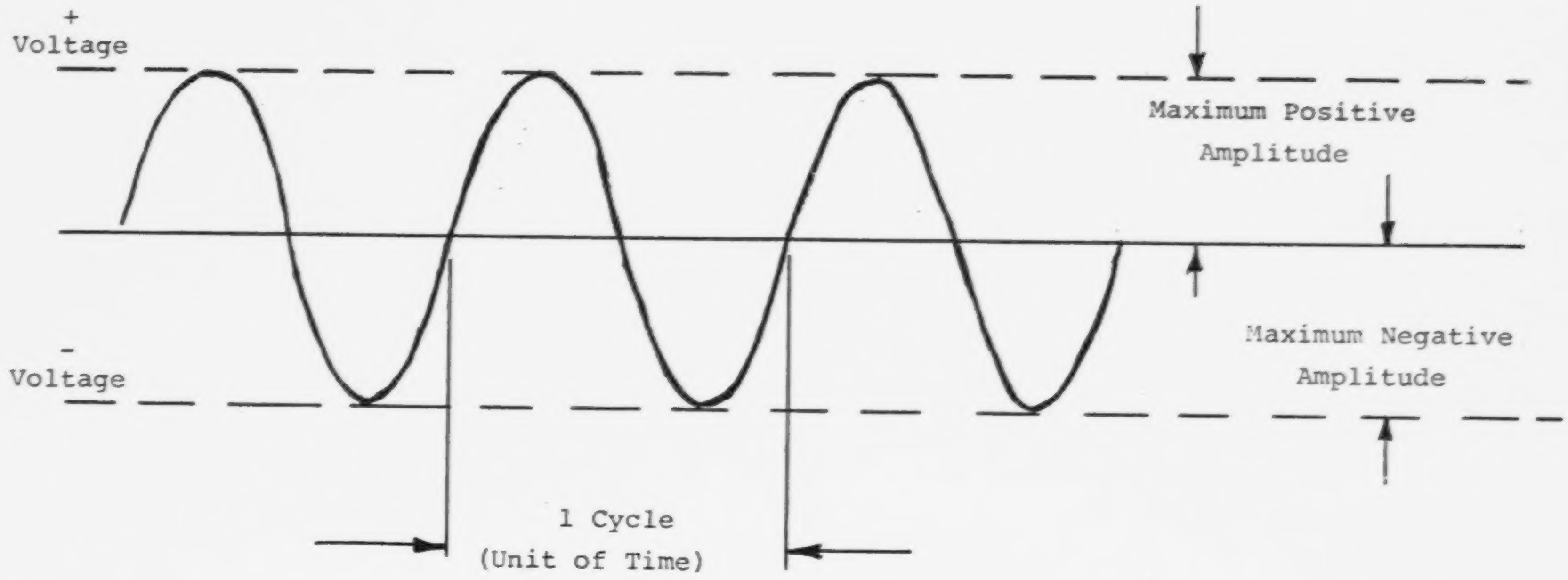

+
Voltage
-
Voltage
Maximum Positive
Amplitude
Maximum Negative
Amplitude
1 Cycle
(Unit of Time)

Figure 3-4

Unmodulated AC Sine Wave

is the modulating information. Thus, the modulated carrier is actually the total signal communicated. At the receiving end, the carrier and modulating information are separated by a reverse demodulation process and the audio information retained for reproduction.

Thus, in an AM radio broadcast the carrier frequency may be 1000 KHz, while the audio information only ranges up to 15 KHz. This audio modulates the 1000 KHz carrier, "rides along" as part of the broadcast signal, and is separated out again at the radio receiver to produce the desired sound from the speaker.

AM is used for most commercial radio broadcasting, since it was developed before FM historically, and the rapid growth of radio in the 1920's and 1930's forced standardization. As an information transmission technique, however, AM has the drawback of being highly susceptible to electrical interference, noise and distortion. Most electrical disturbances, whether due to power fluctuations, lightning, atmospheric disturbances, etc., will affect the instantaneous amplitude of a signal more drastically than its frequency. Consequently, AM broadcasts inherently are more "static-prone" than FM.

Equipment costs for both transmission and reception of AM are, however, lower than for FM and thus present an advantage where noise-free reproduction is not a critical requirement. AM transistor radios, as an example, are available for as low as $5 each, as compared to 3-4 times that price for an equivalent FM model.

3-4.2.2 Frequency Modulation (FM)

If, in Fig. 3-4, the audio signal is made to modulate the frequency of the carrier rather than its amplitude, the process is called Frequency Modulation. Usually the carrier is made to "swing" (deviate) above and below its unmodulated nominal frequency at a rate proportional to the amplitude of the modulating signal, and by an amount proportional to the frequency of the modulating signal (although many other techniques are possible). Thus, to transmit a 15 KHz audio range would require ±15 KHz deviation around the FM carrier.

As noted, FM's chief advantage is a higher immunity to noise and static, as many FM radio devotees will testify. FM is also used for the sound portion of commercial television, although, paradoxically, the picture portion utilizes AM to conserve assigned frequency spectrum.

3-4.2.3 FM Multiplex

One relatively new concept in FM broadcasting, which has significant educational potential is the technique of"FM multiplexing" permitted by the FCC under the Subsidiary Communications Authorization (SCA) in 1955, but coming into widespread utilization only lately.

FM multiplexing is an electronic method of placing two or more separate signals onto a single assigned FM channel, in effect permitting an FM station to broadcast two or more different signals simultaneously. The "subsidiary" signal is "piggy-backed" on the primary FM signal.

Most FM listeners are familiar with "stereo multiplex" in which separate portions of the transmission band are allocated to "left" and "right" sections, representing the different sounds heard from different locations in an orchestra. Also possible, however, is the carriage of signals which have no relation to each other.

Fig. 3-5 illustrates the FM multiplexing technique. A standard FM station operates within a 200 KHz band, 100 KHz on each side of the assigned carrier frequency. Of the 200 KHz, only 30 KHz (±15 KHz around the carrier) are used for the primary FM signal.

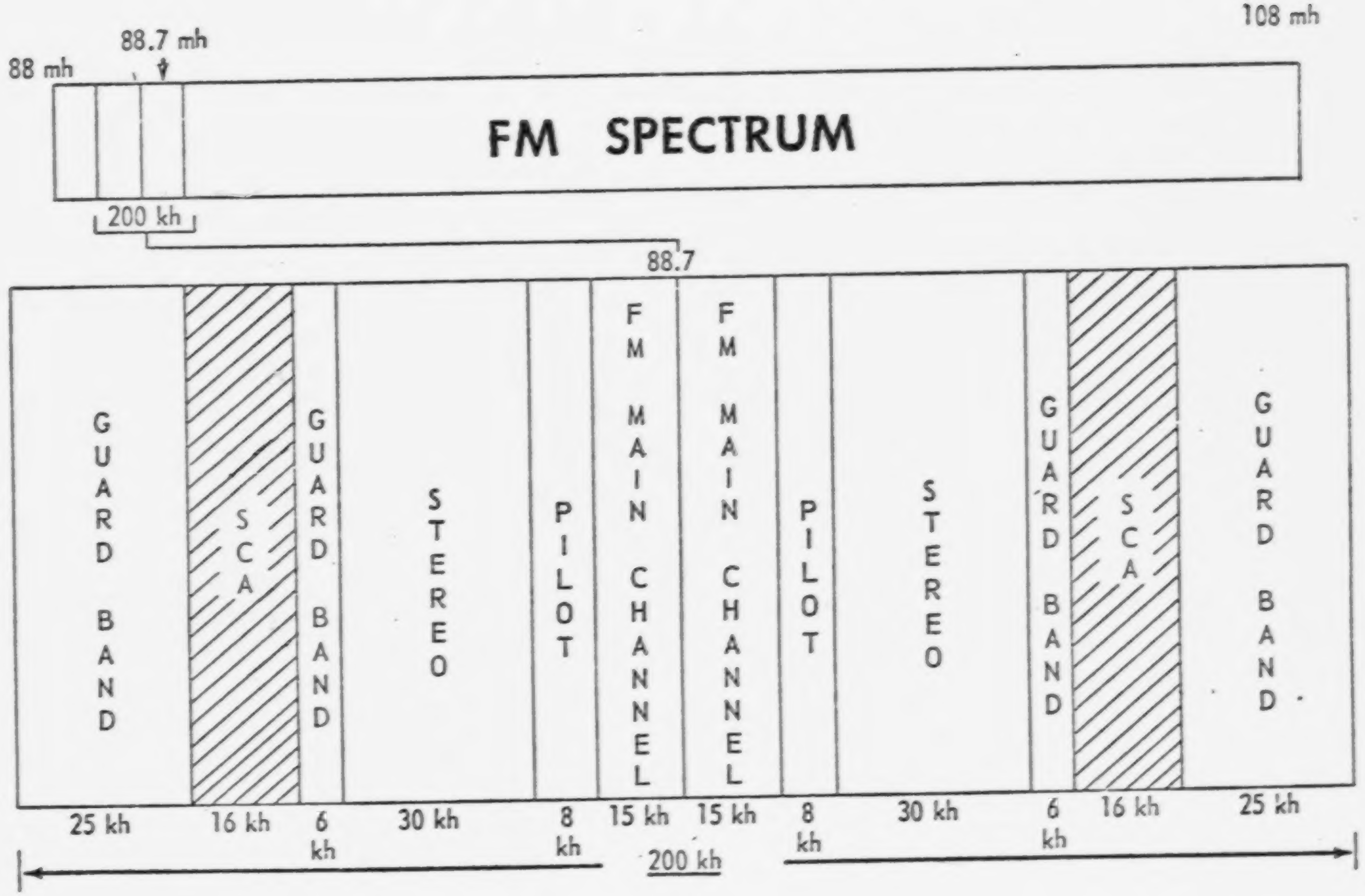

88 mh
88.7 mh
108 mh
FM SPECTRUM
200 kh
88.7
GUARD BAND
SCA
GUARD BAND
STEREO
PILOT
FM MAIN CHANNEL
FM MAIN CHANNEL
PILOT
STEREO
GUARD BAND
SCA
GUARD BAND
25 kh
16 kh
6 kh
30 kh
8 kh
15 kh
15 kh
8 kh
30 kh
6 kh
16 kh
25 kh
200 kh

Figure 3-5

FM Multiplexing

When stereo is broadcast, four additional subchannels are used as shown, a pilot channel (which provides a synchronous signal to coordinate the stereo and main channel signals) and a stereo subchannel on each side of the carrier. When guard bands are added to separate the various signals, there still is left two 16 KHz subchannels, cross-hatched "SCA", one on each side of the carrier.

This SCA frequency spectrum can be used for broadcasting a signal or message completely different from the main and stereo signals. To receive the SCA message, however, a special receiver is necessary to eliminate the surrounding FM main and stereo subchannels. This receiver is a non-tunable device costing about $100, and can receive only the SCA signal from a specific transmitter.

Originally SCA was authorized to help FM stations financially. The SCA subchannel actually transmitted music to special receivers in restaurants, stores, etc., for a fee and thus was a wireless competitor to Muzak.

In 1961, the FCC authorized SCA operations for educational purposes, and since that time a number of educational and/or instructional programs have been multiplexed and transmitted from both commercial and educational FM stations.

3-5 Educational Applications

Because of the almost-universal availability, over many years, of audio equipment and distribution systems (telephone, radio, disc and tape recorders, stereo, etc.), the greatest progress to date in applying educational technology has, naturally, occurred in the audio area.

Obviously, any subject which can be taught in the classroom adequately without the need for visual demonstration is also a candidate for remote audio instruction through telecommunications.

Some subjects are particularly compatible, such as:

(a) Foreign languages
(b) Music
(c) Poetry (and some forms of drama where the stage action is less critical)
(d) Stenography

It may even be true that for this type of subject, remote aural presentation is more conducive to learning than direct classroom instruction, since the classroom distractions are eliminated. So, however, is the interactive capability to ask questions and explain the material, unless the telecommunications system provides interactive capability too.

Almost all educational applications of audio telecommunications are designed for one or both of the objectives previously cited:

(1) to store the aural information for later reproduction and use
(2) to permit reproduction at one or more remote locations

The first objective is attained through storage on the audio disc or magnetic tape, with the capability for playback at any future time. It does not, in fact, necessarily require a telecommunications link, since the stored program and the playback device can both be moved physically to wherever the user is located.

Although not technically an application of telecommunications, this mode is important educationally. The rapid growth in the preparation and sale of in-home instructional material, already a major industry, has been enhanced by the increased convenience of audio cassettes and cartridges.

For some considerable portion of the population, such as the handicapped or aged student located in a remote, isolated geographical area where the cost of telecommunications would be excessive, the physical delivery of program material (particularly when, in the future, video as well as audio cassettes become available) may represent the most practical solution to education.

Where the primary objective is to disseminate audio material simultaneously to a number of remotely located users, a cost-effective choice must be made from the available equipment and communications links. The latter are reviewed in Section III.

Examples of integrated audio educational systems utilizing telecommunications are provided in Chapter 10 of Section IV.

CHAPTER 4. VIDEO

4-1 Component Categories

As for audio, the major video components utilized in educational telecommunications systems function either (1) at the information source, or (2) at the information receiving point, and are involved, respectively, in the visual-to-electronic and electronic-to-visual conversion processes. Fig. 4-1 illustrates the functional elements of a video communication system, and it can be noted that it is identical to Fig. 3-1 except for the substitution of video conversion and storage components.

At the information source, the most commonly used video components include:

(a) Video Cameras and/or Scanners - which change visual images into electronic signals in a format compatible with the distribution method and the receiving and display equipment.

(b) Secondary Storage Media Equipment - this includes equipment to record and store visual information in a form not directly compatible with the telecommunications system. Examples are motion picture film, slides, or microfilm cameras and projectors, since the photographic data stored on the film must be converted by a video camera into an electronic signal before it can be transmitted to a remote receiving location.

(c) Auxiliary and Support Equipment - this category includes the items necessary to integrate components into a functioning system, such as signal switchers and mixers, amplifiers, control consoles, lighting, video monitors, etc. Though performing support rather than primary functions, they constitute a

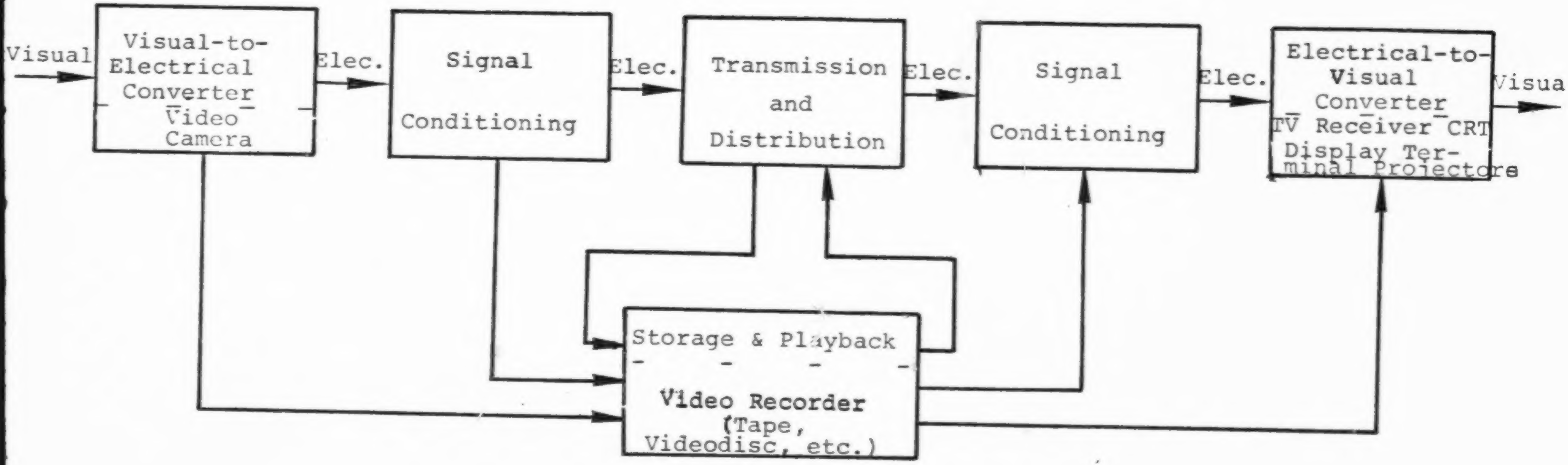

Visual
Visual-to-Electrical Converter Video Camera
Elec.
Signal Conditioning
Elec.
Transmission and Distribution
Elec.
Signal Conditioning
Elec.
Electrical-to-Visual Converter TV Receiver CRT Display Terminal Projectors
Visua
Storage & Playback
Video Recorder (Tape, Videodisc, etc.)

Figure 4-1

Video Telecommunications

significant portion of the communications system cost and complexity.

At the receiving end, the key components are:

(a) Video Receiver/Display Units - which convert the electronic video signals back into a visual display. Included are TV receivers and Cathode-Ray Tube display terminals.

(b) Auxiliary and Support Equipment - At the receiving and display sites, this group includes components such as large-screen and TV projection equipment to improve or enlarge the display.

At either the source or the receiving end, or, indeed, at any other point in the communications system, the ability to store and playback at a later time the video information, is highly desirable. Thus, the category of "video recorder/player" is important. At the user's location, the cost and complexity must be at a minimum, since many users and locations usually are involved. The new, low-cost "home" or cassette/cartridge/disc video recorder/players is therefore of special interest for educational applications.

4-2 Visual-to-Electrical Conversion

The process of converting visual information into electrical form and later reconstructing the original images is considerably more complex than that for aural information. Both the manner in which the human eye operates, and the larger number of variables involved in visual material combine to make this so.

In the latter category, such factors must be considered as:

(a) Color Content (or, if reduced to monochromatic, the "scale of gray" which provides contrast in tone and and shading).

(b) Resolution - essentially the smallest visual increment to be displayed to the viewer.

(c) Orientation in Space and Time - how the image is changing (e.g., a man walking) with respect to space and time and whether these changes must be viewed at the exact time they occur (real-time communications).

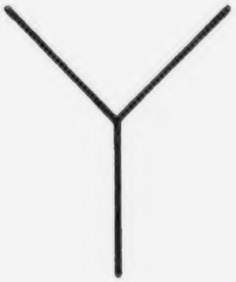
Any method of presenting "reconstituted" visual information to a viewer must either reproduce these factors in a fashion sufficiently accurate so that the viewer's eye will consider them as "normal", or, alternatively, the viewer may be trained to accept inaccurate reproductions as representative or symbolic of the original. In the latter case, an example might be a black-and-white photograph, film or TV program accepted as a substitute for the original color images. The viewer knows that the reproduction has this color limitation, but is conditioned to accept it as not significant.

Most methods of visual-electrical conversion consist of breaking the image into a large number of incremental quanta of information, and, after transmission, reconstructing the image by assembling the quanta together again, like a jigsaw puzzle in concept.

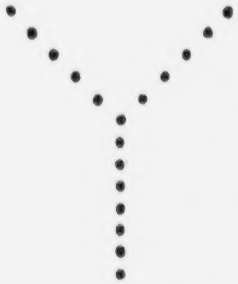
Fig. 4-2 illustrates the technique, with the "Y" of (a) representing an image which must be converted to electrical form and later reproduced.

Fig. 4-2 (b) shows the same "Y" as an assembly of dots rather than unbroken lines. Obviously, some portion of the original information has been lost, but if the dots are close enough this loss can be held between visually acceptable limits.

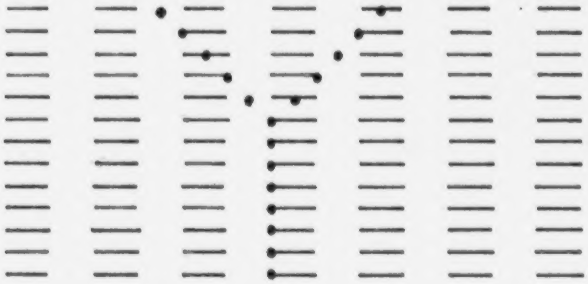
This dot pattern reconstruction is used in photography and printing. In photography, the emulsion on any film is not continuous but, if magnified sufficiently, can be seen to be a matrix of dot-like deposits. The size and spacing of the matrix is a measure of the "grain" of the film which,



(a) Original Visual Information



(b) Reconstructed Information - Dot Pattern



(c) Reconstructed Information - Line Pattern

Figure 4-2

Techniques for Reconstructing Visual Information in turn, determines the resolution of the picture, and how much it can be enlarged before the spacing between dots becomes objectionable.

Similarly, in printing of halftone photographic material, the picture is "screened", which results in the printing of a pattern of dots rather than a continuous variation in black-white intensity. Again, under magnification the dots become clearly visible.

When a visual image is converted for the purpose of sending it electronically to a remote location, there must be some agreed-upon "code" or method of breaking up the image so that it can be reconstructed properly at the receiving end. This coding process is called "scanning".

The method of scanning used in broadcast TV is illustrated in 4-2 (c), and consists of viewing each incremental portion of the image in an orderly sequence of individual, closely-spaced horizontal lines. This is by no means the only acceptable scanning pattern (facsimile, for example, uses a helical scanning pattern), but simply the accepted standard for commercial TV.

Fig. 4-3 shows the line scanning pattern in more detail. For TV(in the U.S.), 525 lines are scanned per "frame" (an image which fills the TV screen) and 30 frames are scanned per second, so that a total of 15,750 lines are scanned per second.

Two interlacing "fields" of 252½ lines each combine to make one frame. During the scanning of one field, the video camera will electronically "look" first at line 1, starting with 1a at the left side and progressing along the line to 1b at the right. This is actually accomplished within the camera by forcing an electron beam to swing across a Cathode-Ray Tube screen, upon which is projected the visual image taken by the camera. The variation in light intensity of the image is sensed during the scan of the line, and converted into a proportionally varying electrical signal.

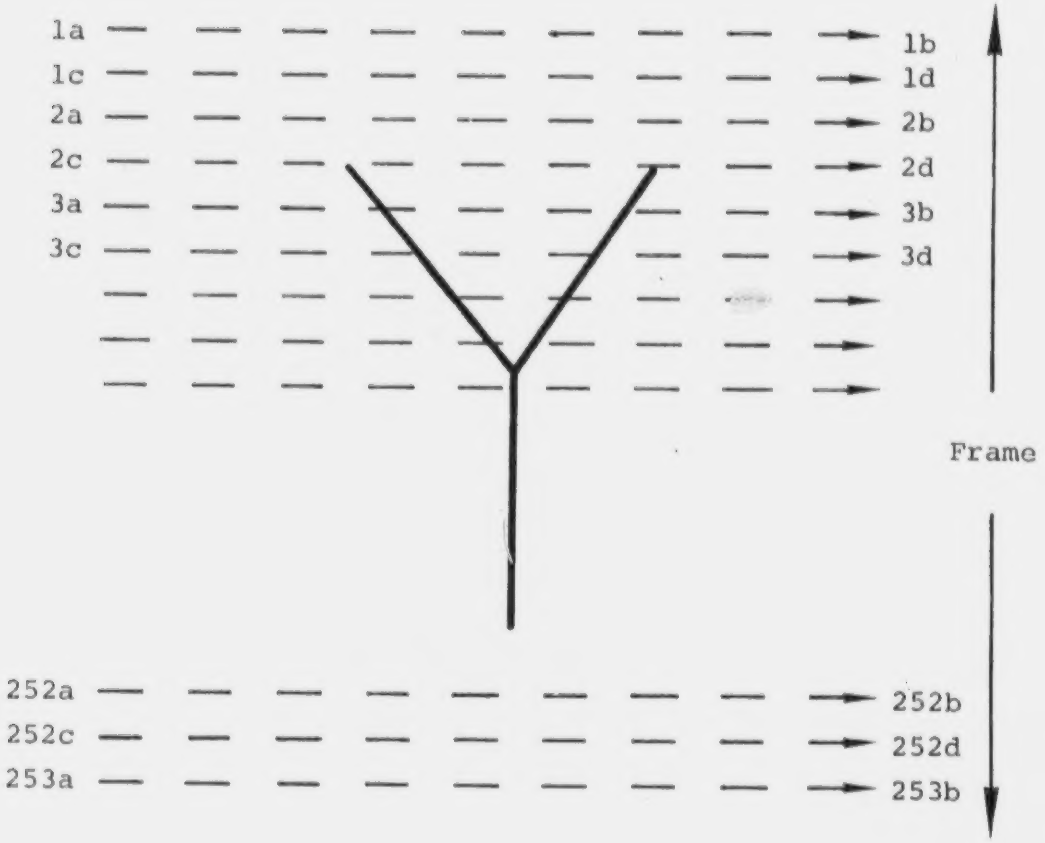

1a
1b
1c
1d
2a
2b
2c
2d
3a
3b
3c
3d
Frame
252a
252b
252c
252d
253a
253b

Figure 4-3

Video Camera Scanning Pattern

After line 1a-b has been scanned, the electron beam is lowered slightly and swung back to point 2a. During this "retrace" time, the beam is turned off to prevent scanning extraneous information. Line 2a-b is scanned identically to line 1a-b, and in sequence, all of the first field is scanned similarly. This occurs in 1/60 second. The second field (lines 1c-d, etc.) is then scanned in an identical manner to produce the 525-line frame.

At the end of the frame, the beam is turned off and returned to point 1a. This takes a longer time than a "retrace" of one line position, and is called a "blanking interval". After the blanking, a second frame is scanned and the process continues indefinitely.

Again, it is emphasized that this particular pattern has no inherent advantage over others that can be devised. Since, however, it is the standard of U.S. television (other countries, particularly in Europe have other standards), it forms the basis for most video equipment presently on the market.

In some non-TV applications, the TV standards are a handicap. For example, the ratio of horizontal to vertical picture size selected as desirable for TV is not suitable to cases where it is desired that vertical and horizontal resolution be equal.

Educators, therefore, should consider their specific application carefully. If the visual information is not going to be displayed on standard TV receivers, there may be better alternatives to the use of TV-compatible equipment.

4-2.a Video Cameras and Scanners

As indicated by the foregoing discussion of visual-to-electrical conversion, a video camera is basically a combination of a portion of a motion-picture film camera with an electronic scanning device.

The "input" section of the video camera includes a lens to focus the picture and project it to a point inside the camera housing. The lens may be supplemented with view-finder and "zoom" attachments as in a film camera.

Instead of the image being focused on a moving film, however, it is projected onto the screen of the camera "pickup" tube, from which it is scanned and converted into a varying electrical signal, as outlined above.

Two major types of camera pickup tubes have been used to date, the "Image Orthicon" and the "Vidicon" (although the latter is undergoing some recent competition from the "Plumbicon", developed by N.A. Philips).

The Image Orthicon is much more sensitive and will operate at relatively low light levels, and therefore has become the standard for professional TV camera use. The tube alone may cost $1,000 - $2,000, and the entire camera usually ranges in cost from $15,000 - $25,000 for black-and-white, and as high as $75,000 for a broadcast quality color unit.

The Vidicon tube offers low cost and long operating life, and is therefore popular for school and semi-professional use. A Vidicon replacement tube costs $200 - $500, while complete cameras are available as low as $500, up to $5,000 - $10,000 for the deluxe black-and-white models, or $10,000 - $20,000 for color.

The basic disadvantage of the Vidicon tube is that it requires high ambient light levels. Thus, its use outside of the well-lighted studio is severely restricted.

Table 4-1 lists the key characteristics of both camera types. In most cases, educational usage has featured the Vidicon camera because of its cost advantage, with a few of the more well-financed institutions, with near-professional facilities, using the Image Orthicon units.

Fig. 4-4 illustrates the external components and controls of a typical video camera, with view-finder/monitor display and zoom control. The view-finder is a Cathode-Ray Tube monitor which allows the operator to see exactly what is being

	Image Orthicon	Vidicon
Cost	High: $1,000-2,000 per tube $15,000-25,000 per camera (b&w) Up to $75,000 for professional-quality color camera.	Moderate: $200-700 per tube $500-10,000 per camera (b&w) Up to $20,000 for professiona quality color camera.
Tube Life	About 1,500 hours.	About 5,000 hours.
Required Light Levels	Good for low/moderate light levels; can be damaged at high light levels	Good only at high light levels; will "smear" otherwise.
Operating Convenience	Requires more experience to operate (e.g. prolonged focus on stationery image may "burn" tube).	Easier to operate. More rugged.
Major Applications	(1) Highest quality image production. (2) Low-light level use.	(1) General purpose use when budget is restricted. (2) Use in film chains where light level is high.

Table 4-1

Relative Advantages of Image Orthicon and Vidicon Camera Tubes

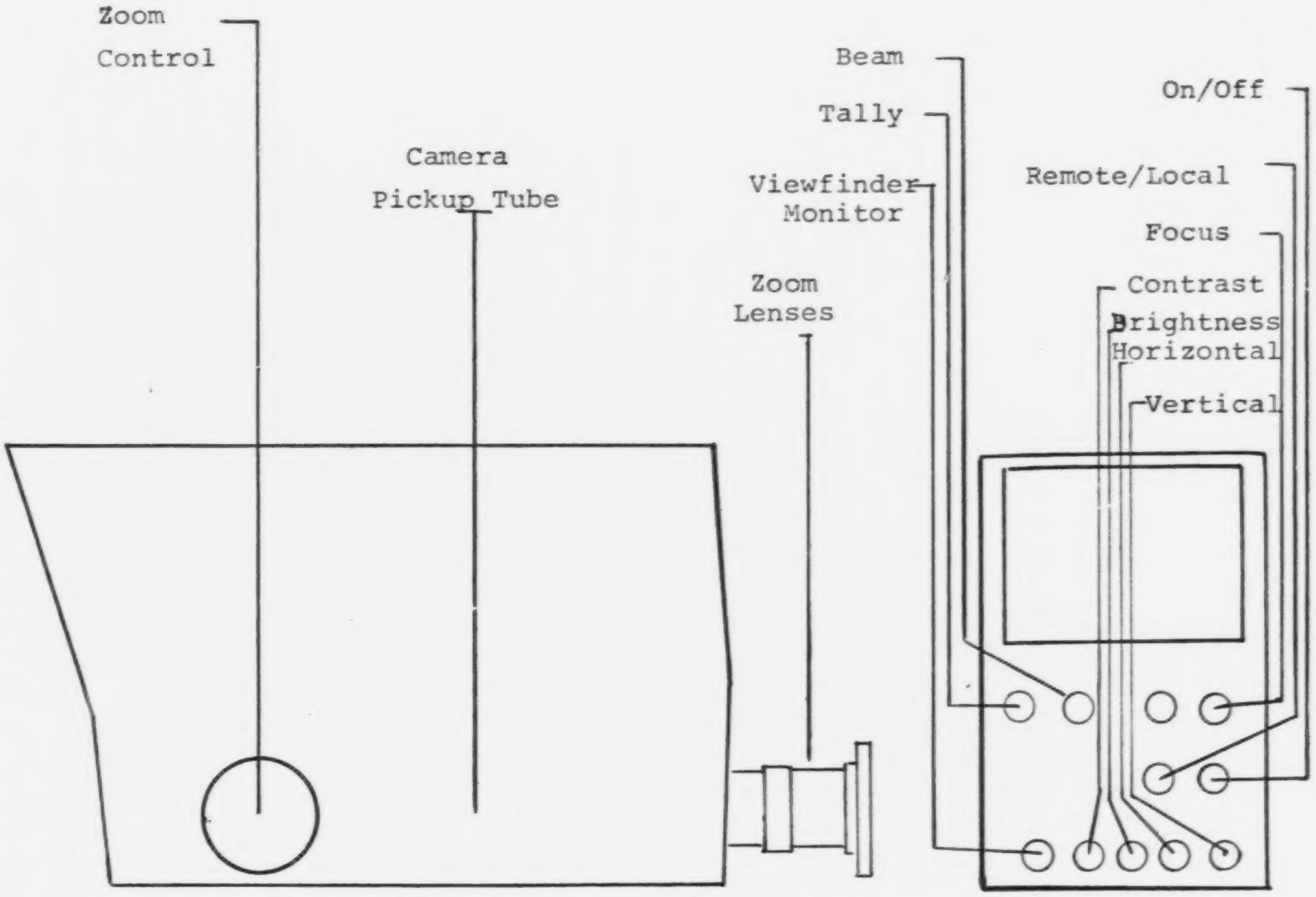

Zoom
Control
Camera
Pickup Tube
Zoom
Lenses
Viewfinder
Monitor
Beam
Tally
On/Off
Remote/Local
Focus
Contrast
Brightness
Horizontal
Vertical

Figure 4-4

Video Camera - Typical Components and Controls photographed, while the zoom crank permits rapid transition from long shot to closeup, and vice versa.

The electronic controls, it may be noted, resemble those of TV, which is natural since the electronic signal into which the image is converted is designed to be compatible with a standard TV receiver. Thus, "focus", "contrast", "brightness", "horizontal hold" and "vertical hold" have exactly the same functions as they do on a home TV set.

The configuration shown is that of a black-and-white video camera. For color, many of the components are triplicated, resulting in a much more complex and expensive unit. Typically, a color comera will incorporate a precision optical system which takes the image from the camera lens and splits it into three parallel primary color-beams (red, blue and green). Three separate pickup tubes are used, each designed for peak efficiency over its own primary color spectrum, and each with its own scanning and signal generation electronic circuitry. The three signals are maintained independently throughout whatever transmission or recording facilities are involved, and recombined on the viewer's color TV receiver to form the original image.

This redundancy of components, together with the great care necessary to establish and keep the correct balance and proportion of the three color signals throughout the complete system, is the reason for the substantial difference in the cost between monochromatic and color television.

4-2.a.1 Special-Purpose Scanners

The "normal" video camera is designed to produce an output compatible with a broadcast TV signal (except for the RF carrier), and thus is most suitable for visual information with a relatively high degree of motion, i.e., equivalent to a motion picture film.

There are many applications, particularly in education, where visual information is static or has relatively little motion. Examples are displays of graphical or alphanumeric data, photographs, microfilm images, etc.

In these cases, both the scanning technique and the image conversion tubes used for TV-compatible video are wasteful of bandwidth, and other special-purpose scanning systems are used.

Facsimile, one of these special systems, is described in Chapter 5. It is limited, however, to information where the original is in document form, and has no selective editing capability.

More versatile is the storage or "scan converter" tube, and scanning systems which can be used in conjunction with it. The scan converter is essentially a Cathode-Ray Tube which displays an electrical signal on its face in a standard manner, but with a long-persistence screen and with associated electronics that permits erasure and rewriting of either the entire image or selected portions, on command.

Thus, the scan converter can be used as a "frame grabber" or picture-freezing display, holding its image for any desired length of time. A video camera might be used to scan the image in a single frame, transmitting this frame to a remote location. The viewer, for example, in a retrieval system, could read one page which remains motionless until replaced by a second page.

Although the standard TV system can also peform this function, it would be inefficient, having to "reshow" the same page 15,750 times per second to maintain the image. With a stored-memory system, however, the picture need only be converted once. During the time one viewer is looking at his display, the system can supply other fixed-frame displays to many other viewers. An example of this type of frame-retrieval system is described in Chapter 11.

Complete memory systems, incorporating the scan converter tube, are available from Hughes Aircraft, and others, ranging in cost from $3,000 - $10,000. With suitable input/output and control circuitry, they can form the basic storage and editing component of many educational systems, such as computer-aided-instruction, information retrieval, computer graphics and data communications.

4-2.b Secondary Storage Media Equipment

Much of the visual information which must be transmitted to remote locations is stored on media not directly compatible with the telecommunications system. If a school desires, for example, to use a motion picture film on an instructional TV network, the images stored in photographic form on the film must be converted to electrical signals for transmission.

The technique is similar to conversion of a live visual image, except that special mounting and lighting provisions are included to minimize the degradation involved in transferring the information from one medium to another. If the original medium is motion-picture film, a further requirement is that the speed at which the film moves through the reel while being viewed by a video camera be sychronized with the camera's scanning rate. This means that the 16 frames per second film playback rate must be synchronized with the 15,750 frames per second TV scanning rate in such a manner that the motion on the TV screen appears normal and life-like.

Equipment to perform this film-to-video converstion is termed a "film chain", and consists of film (and/or slide or filmstrip) projectors optically linked to a video camera. When several projectors are linked with one camera, combinations of mirrors and prisms known as "optical multiplexers" are used to admit only the desired projector beam into the camera lens.

The costs of a film chain are from $3,000 - $10,000 for monochrome, and $10,000 - $50,000 for color.

Also available is equipment to perform the reverse function, such as converting images stored on video tape to film. These units play back the taped information into a monitor screen, usually designed for high brightness. A film camera photographs the image from the face of the screen, again maintaining speed synchronism.

This technique was used in the early days of TV, before video tape was developed, to produce "kinescope" film recordings of live TV broadcasts. Recent equipment, however, produces substantially better quality film than represented by those examples.

Black-and-white video-to-film recorders cost from $10,000 - $20,000 while color units are in the $50,000 - $75,000 range.

4-2.c Auxiliary and Support Equipment

For any video studio facility which must operate under flexible conditions, the basic camera and film chain equipment must be supported by a variety of auxiliary and control components.

Typical support equipment includes:

(1) Video Switches - As shown in Fig. 4-5, video signals may originate from a number of sources such as video cameras, video tape recorders or film chains. All of these are connected into the video switches where, by pressing the appropriate pushbutton, only the selected signal is permitted to proceed through the system. In a commercial TV broadcast, the director will select those images, in sequence, which he believes will result in the most interesting program.

(2) Audio Mixer - The audio mixer, illustrated functionally in Fig. 4-6, accepts a variety of audio inputs in a manner similar to the video switches. Most applications, however, require the mixing (simultaneous transmission) of a

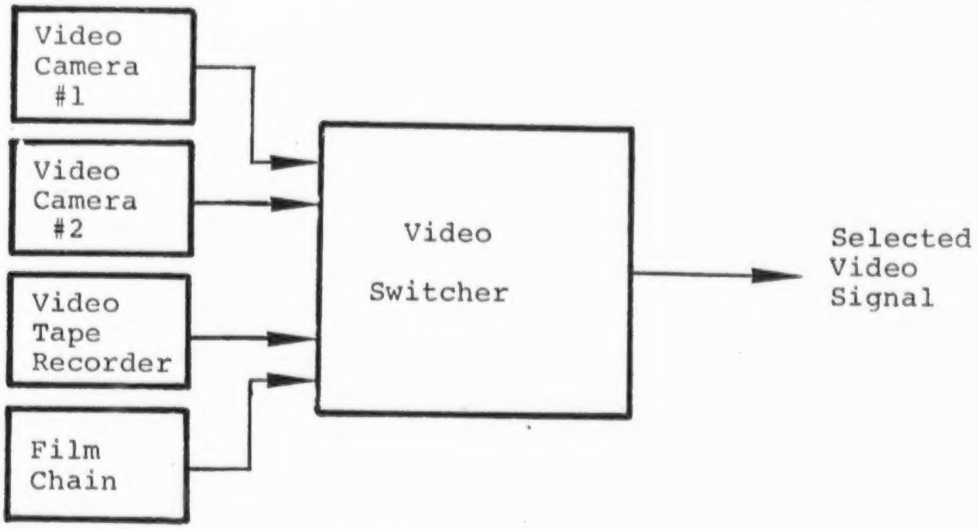

Video Camera #1
Video Camera #2
Video Tape Recorder
Film Chain
Video Switcher
Selected Video Signal

Figure 4-5

Video Switcher Operation

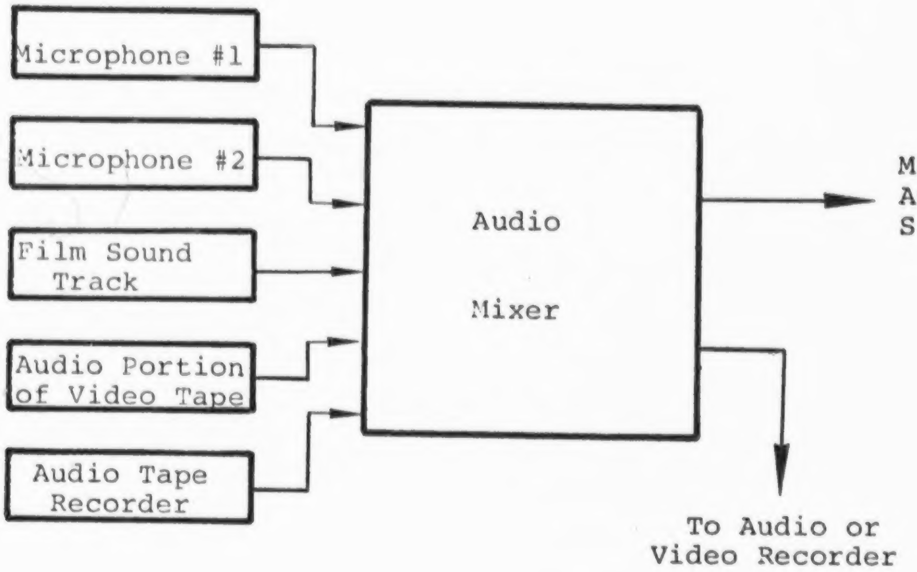

Microphone #1
Microphone #2
Film Sound Track
Audio Portion of Video Tape
Audio Tape Recorder
Audio Mixer
Mixed Audio Signal
To Audio or Video Recorder

Figure 4-6

Audio Mixer Operation

number of audio signals rather than the selection of only one. For example, a panel discussion may feature several speakers, each with his own microphone and all voices must be heard, even when speakers are talking at the same time. Thus, although the capability to choose only one audio signal and exclude others is present, this is not the normal mode of operation.

Both the video switches and audio mixer, in addition to selecting signals, provide the ability to balance the signals against each other so that switching does not result in any disproportion.

(3) Video Monitors - These are display units which permit the studio operators to look at what is being scanned by any camera (or other video source) at any time, so that the desired selection can be made. They also serve to indicate malfunction if it occurs. The monitor unit is the equivalent of a TV receiver with the RF and channel tuning sections omitted.

(4) Special Effects - Equipment is available to produce a variety of special effects, such as:

(a) Dissolve - which allows variation of the camera output signal from full intensity to zero, producing an image which fades away (dissolves) or, conversely, fades in from a blank screen.

(b) Insert or Superposition - which permits inserting one image over another at any designated location. The split-screen effect is a variation of this.

(c) Wipe - permitting an image to be wiped away sequentially, as, for example, disappearing from left to right across the screen.

(5) Lighting - Lighting equipment may range from a basic minimum package of two or three floodlights, with adjustable stands, to a very expensive complex of lights, filters and controls designed for televising, for example, a costume play in color where the various actors, costumes and portions of the set require individual illumination.

To illustrate the wide range of costs possible for a total video studio package, Table 4-2 lists the components of four systems offered by Audiotronics Corp., designed for the lower-cost educational applications, and three systems offered by RCA, which are closer to professional broadcast quality. The cost variations, from a low of about $2,000 to a high of over $100,000, indicate that equipment is available for almost every budget.

4-3 Electrical-to-Visual Conversion

Video electrical signals are most generally converted back into visual form by utilizing a Cathode-Ray Tube (CRT) as the basic conversion device. A CRT is a vacuum tube with one end shaped in the form of a relatively flat surface (see Fig. 4-7), which may be either rectangular or round. The inside of this flat surface is coated with phosphorescent material which emits light when struck by a high-energy beam of electrons.

At the narrow end of the CRT, an "electron gun" is provided. This is a group of components which include:

AUDIOTRONICS				RCA		
Micropak	Modpak	Multipak	Maxipak	Economy Monochrome TV Studio Package	Color-Convertible Monochrome TV Studio Package	Medium Color TV Studio Package
(1) Monochrome Video Camera	(1) Monochrome Video Camera, with view finder & zoom lens	(1) Monochrome Video Camera, with view finder & zoom lens	(2) Monochrome Video Cameras, with view finders & (2) zoom lenses	(2) Monochrome video Cameras	(2) Monochrome Video Cameras (color convertible)	(3) Color Video Cameras
				(1) Film System Monochrome	(1) Film System, Monochrome	(1) Color Film System
(1) Video Tape Recorder, Monochrome	(1) Video Tape Recorder, Monochrome	(1) Video Tape Recorder, Monochrome	(1) Video Tape Recorder, Monochrome with electronic editing	(1) Video Tape Recorder, Monochrome	(1) Video Tape Recorder, Monochrome	(2) Video Tape Recorders, Color
			(1) Video Switcher	(1) Video Switcher	(1) Video Switcher	(1) Video Switcher
			(1) Audio Mixer	(1) Audio Mixer	(1) Audio Mixer	(1) Audio Mixer
(1) Video Monitor 16-inch	(1) Video Monitor, 19-inch	(1) Control Console with monitor & Pedestal	(1) Control Console with Program & Preview Monitors, Distribution Ampl.	(1) Control Console	(1) Control Console	(1) Control Console
				(1) Lighting Package	(1) Lighting Package	(1) Lighting Package
Cables, Mike, Tripod	Cables, Mike, Tripod, Dolly	Cables, Mike, Pedestal	Cables, Mikes (2), Tripod, Dolly, Pedestal	Cables, Tripods, Mikes, Stands, etc.	Cables, Tripods, Mikes, Stands, etc.	Cables, Tripods Mikes, Stands, etc.
$2,000	$2,600	$3,600	$6,500	$21,000	$37,000	$105,000

Table 4-2

Typical Studio Equipment Costs

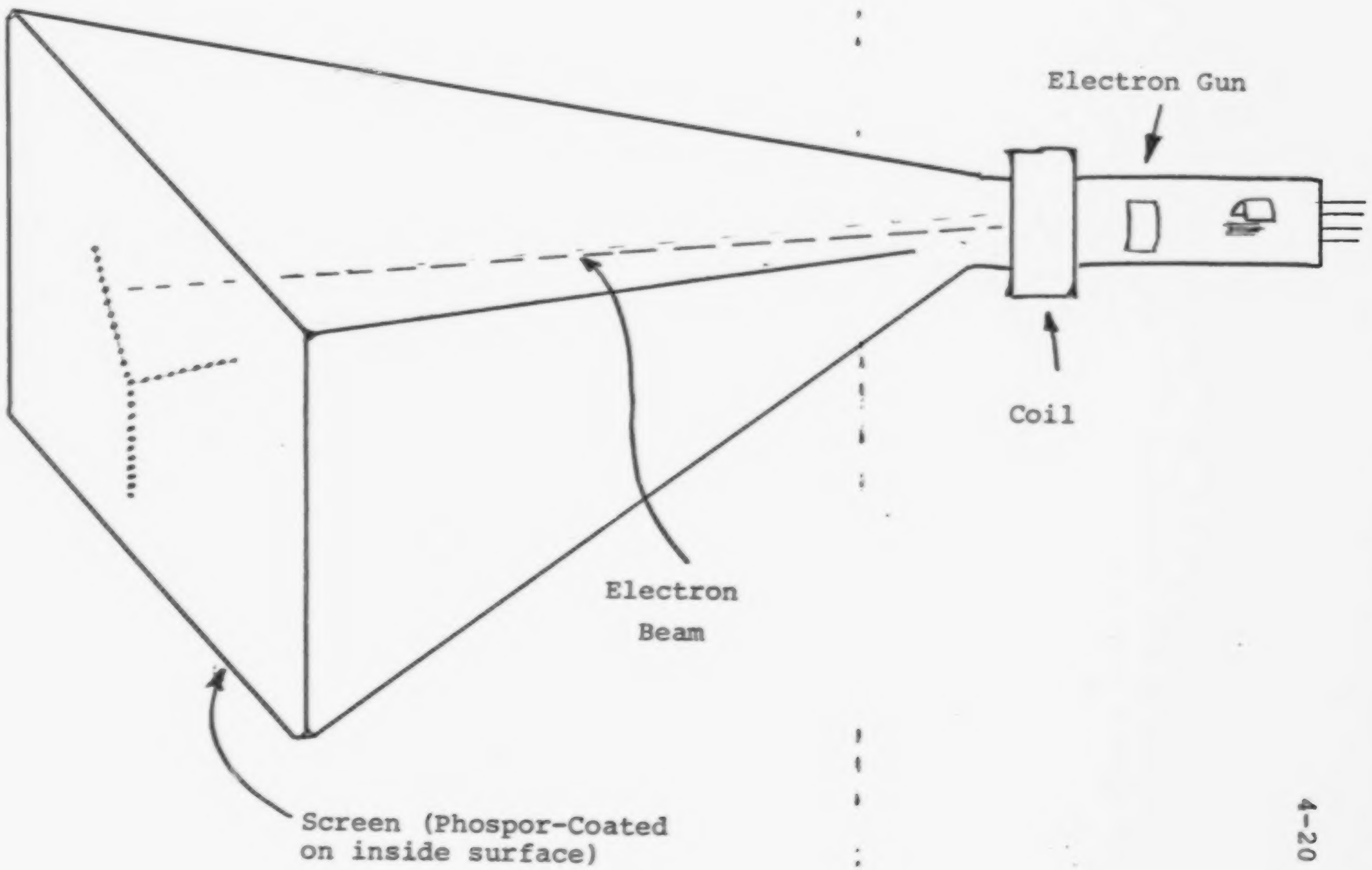

Electron Gun
Coil
Electron
Beam
Screen (Phospor-Coated
on inside surface)

Figure 4-7 Cathode-Ray Tube

(a) A cathode which emits electrons.

(b) An anode, at a high positive voltage, to accelerate the electrons down the neck of the tube toward the screen. The anode is shaped (in a mesh, for example) to permit most of the electrons to pass through it rather than be halted.

(c) Means for forming the beam, usually by a focus coil which can be adjusted externally.

(c). Means for deflecting the beam horizontally and vertically to reach any point on the screen. This is accomplished either by electrostatic plates, or for the larger size CRT's, by magnetic coils whose fields interact with the electron beam.

For a monochromatic display, the same phosphor is coated all over the screen. A dot of light will be emitted and seen at the point where the electron beam hits the phosphor. How long the light lasts depends upon the "persistence" characteristic of the selected phosphor, which can be from a small fraction of a second to many seconds or even minutes.

For TV applications, the persistence is chosen so that as the beam is deflected, forming sequential dots of light, the total pattern blends together without flicker or smearing.

TV image generation reverses the process described in 4-2. The CRT electron beam, under control of synchronizing signals in the TV set, is made to trace the same 525-line frame pattern in 1/30 second as was traced by the original scanning in the video camera pickup tube. As the beam moves, its instantaneous energy is determined by the strength of the current representing the video information. Thus, along each line of the TV raster, the light intensity (corresponding to shades of gray on a black-and-white tube) will vary in proportion to the video current and, correspondingly, to the original visual information. The resulting dot-and-line pattern of light effectively reproduces the original image.

4-3.a TV Receivers

Although the principles of electrical-to-visual conversion, as described above for TV receivers, are not difficult to grasp, a substantial amount of auxiliary circuitry is necessary in each receiver to actually implement the process.

Fig. 4-8 illustrates the functional components of a TV receiver. The antenna picks up all broadcast TV signals in the area and presents them simultaneously to the input terminals of the set. These signals are in RF form, i.e., the video information is conveyed via an RF carrier frequency. RF frequency assignments are shown in Table 4-3.

When the TV viewer selects a desired channel by turning his channel selector knob, the tuner in the set allows only the desired channel to pass through. This is accomplished by combining an appropriate frequency from an internal oscillator with the incoming RF signals so that the combination of oscillator frequency and desired RF channel produces a specific Intermediate Frequency (IF), to which the TV set is tuned.

This IF is amplified and then detected, i.e., separated from its carrier and split into the separate audio and video components. The audio, as shown, is amplified and energizes a speaker, producing the sound accompanying the picture.

The video signal is also amplified and connected to the CRT where it determines the instantaneous velocity, and therefore intensity, of the electron beam. Synchronizing and blanking signals which are transmitted along with the video are used to synchronize the scanning pattern of the CRT electron beam, so that the picture is properly reconstructed.

For color, three separate video paths, for the three primary colors, are provided. Each drives a separate electron gun on a tri-gun CRT. Further, the CRT screen is coated with three different phosphors, in closely spaced beads, each

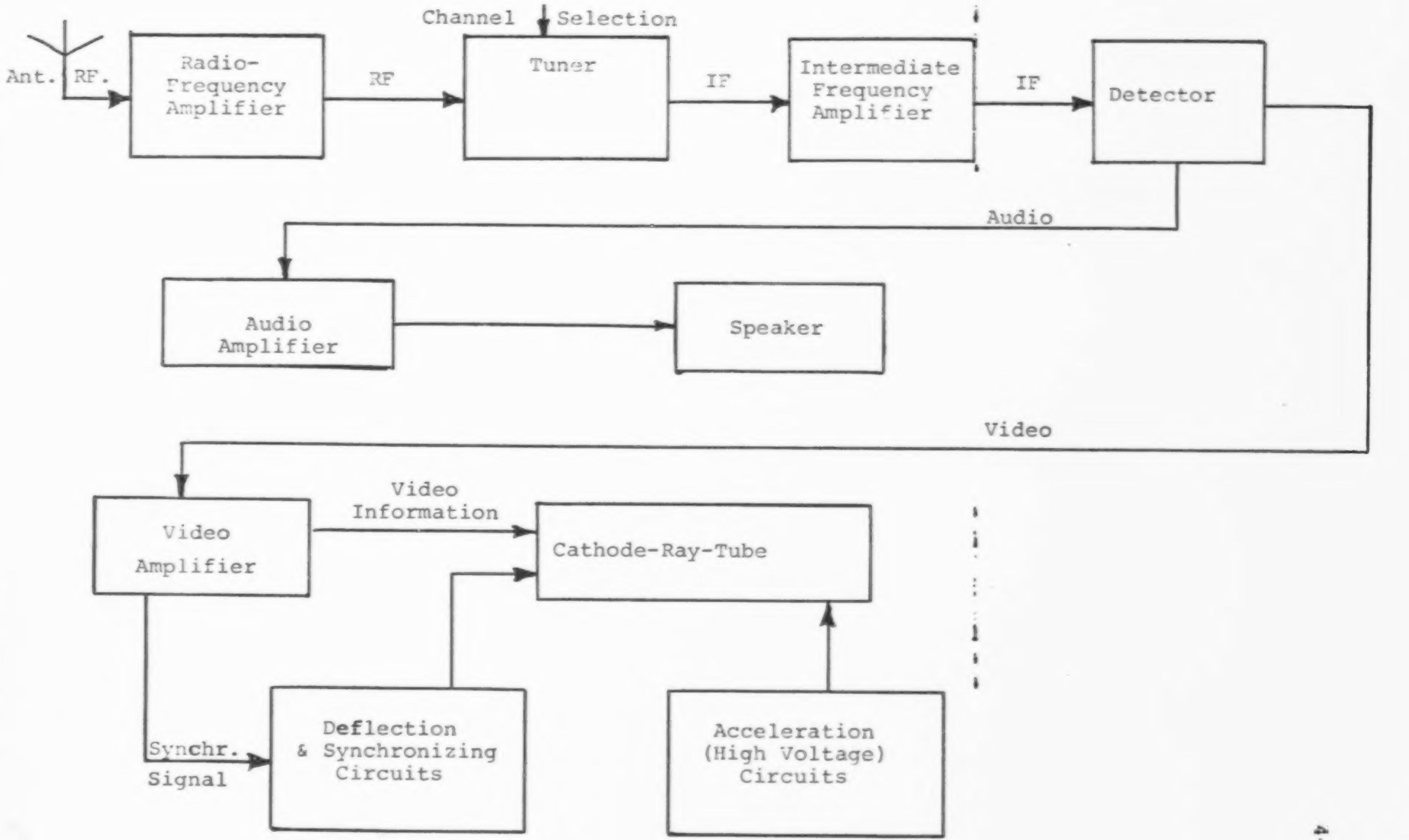

Ant.
RF.
Radio-
Frequency
Amplifier
RF
Channel Selection
Tuner
IF
Intermediate
Frequency
Amplifier
IF
Detector
Audio
Audio
Amplifier
Speaker
Video
Video
Amplifier
Video
Information
Cathode-Ray-Tube
Synchr.
Signal
Deflection
& Synchronizing
Circuits
Acceleration
(High Voltage)
Circuits

Figure 4-8 Functional Elements of a TV Receiver

Channel	RF Frequency Range, MH_z	
2	54 - 60	(VHF)
3	60 - 66	(VHF)
4	66 - 72	(VHF)
5	76 - 82	(VHF)
6	82 - 88	(VHF)
7	174 - 180	(VHF)
8	180 - 186	(VHF)
9	186 - 192	(VHF)
10	192 - 198	(VHF)
11	198 - 204	(VHF)
12	204 - 210	(VHF)
13	210 - 216	(VHF)
14 - 84	470 - 890 (6 MHz per Channel)	(UHF)

Table 4-3

Broadcast TV Channel-Frequency Assignment producing one of the three primary colors when struck by the electrons. Thus, the final picture is actually a superposition of three color sections which blend together to resemble the original.

TV "monitors" used in studio and program production work, are TV receivers without the RF and IF sections, since the signal, before it is modulated and broadcast, is already in video and audio form. Thus, in Fig. 4-8, the antenna, RF amplifier, tuner, IF amplifier and detector would be omitted.

The costs for TV receivers are well known, due to their wide use in entertainment. Black-and-white sets range from below $100 for small-screen models to about $300 for 25-inch screen units. Color models are priced from a low of about $250 to $800 or more for the large-screen, remote-control tuning versions.

4-3.b CRT Display Terminals

Frame display utilizing the TV line-scan format is by no means the only method of electronic-to-visual conversion, but the most widely familiar because of the ubiquitous presence of TV receivers almost everywhere.

The CRT is, however, adaptable to many techniques for controlling what is displayed on the screen. Non-TV CRT devices are termed "CRT display terminals", and presently encompass a broad spectrum of products. Since many CRT display terminals operate in conjunction with, or are controlled by, a computer, they are also included in the discussions of Chapters 6 and 12.

Fig. 4-9 illustrates the functional elements of a CRT display terminal, designed primarily to present graphical and/or alphnumeric information to the viewer. (If an all-purpose receiver is desired, the circuits of the TV receiver of Fig. 4-8 could be added to those of 4-9, with a mode-select capability).

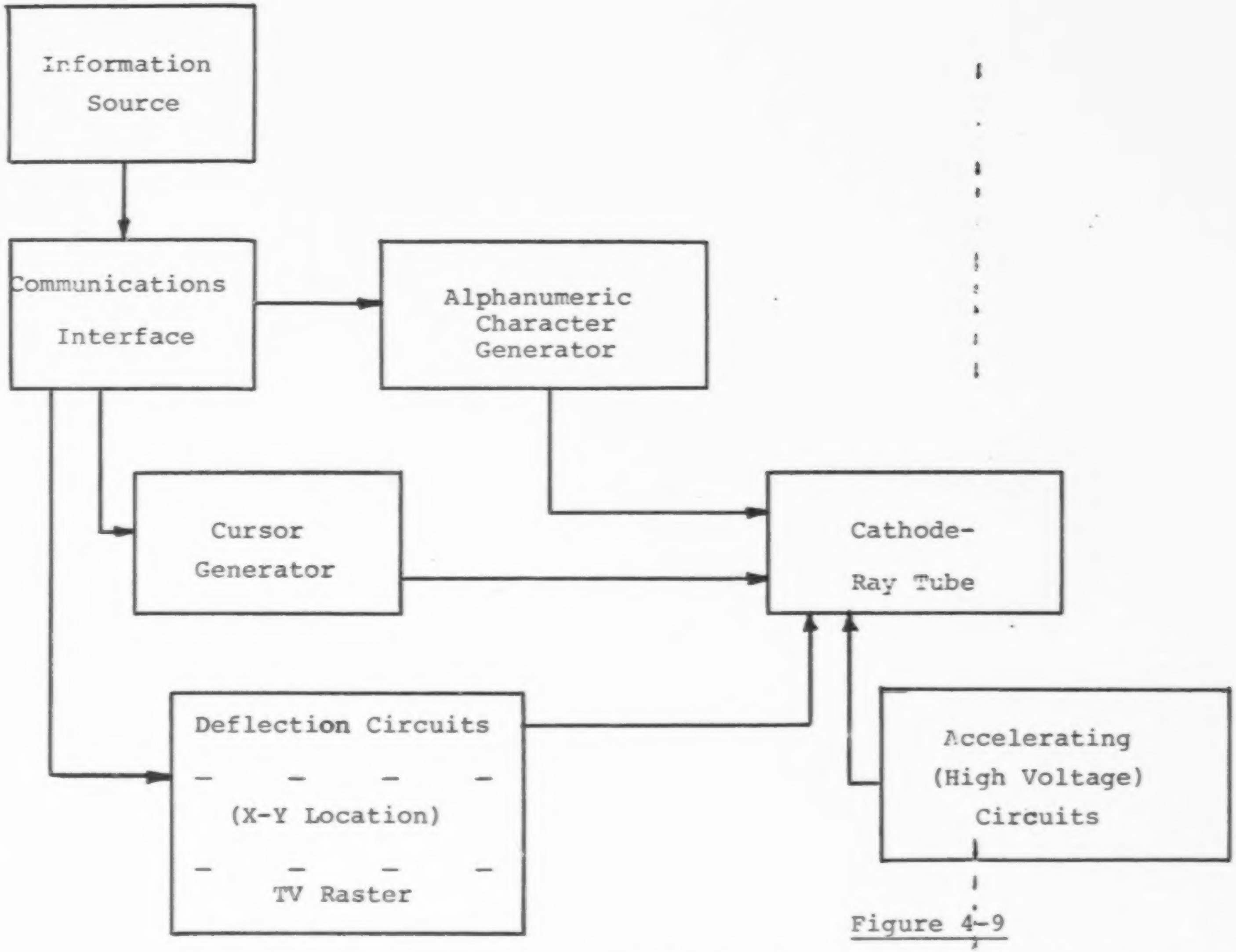

Information Source
Communications Interface
Alphanumeric Character Generator
Cursor Generator
Cathode-Ray Tube
Deflection Circuits
(X-Y Location)
TV Raster
Accelerating (High Voltage) Circuits

Figure 4-9

Functional Elements of A CRT Display Terminal

Information representing a graph or series of alphanumeric characters arrives from the source through a communications interface unit which provides the necessary decoding or format transformation. The information is usually of two kinds, (1) what to display (e.g., dot, letter, number, symbol, etc.), and (2) where on the CRT screen to locate it. The latter is either provided as, or converted into,"X" and "Y" deflection voltages which swing the electron beam the appropriate distance along both coordinates.

If a graph is drawn, the electron beam is swung to the point on the CRT screen where one end of the graph is located. A point of light appears. The beam is then deflected successively through the path necessary to "draw" the graph on the CRT screen.

For alphanumeric characters, each character could be drawn as required by commanding the beam to trace through the required outline. This would be wasteful, however, of information storage space at the source. It is more convenient to store, in the CRT terminal itself, a "character generator" which is programmed, upon command, to force the CRT beam to trace the shape of that character. Letters, numbers and symbols are usually formed by a series of short "strokes" which, together, appear to form the desired character.

Thus, to display the letter "6", a code for 6 is sent to the character generator, while the desired location is sent to the deflection circuits. The output of the character generator will be a series of varying voltages which will produce short strokes of light on the CRT screen, combining to form the shape of a 6.

By means such as this, any kind of visual display can be presented, no matter how complicated. Although Fig. 4-9 shows a one-way "receiver only" terminal, by including inquiry capability, the CRT terminal becomes a two-way device, capable both of requesting and receiving information.

CRT display terminals presently on the market vary in cost from about $2,000 for a minimal 2-way unit, up to $20,000 or more for models designed for complex computer graphics applications.

4-3.c Image Projection

The size and brightness of CRT displays are limited by the tube itself. Since air is evacuated from the CRT, a large tube means a very high total air pressure on the outside surface, which tends to crush the tube unless strong, thick glass is used. At present, CRT screens with a maximum viewable area of about 400-500 square inches are a practical limit, since larger CRT's would be excessively costly.

This results in no more than perhaps 25-40 viewers, or about one classroom, being able comfortably to view a single display. To alleviate this, image projection systems have been designed which enlarge and project the TV image to permit more viewers. Extreme examples are the closed-circuit displays of sports events, such as championship prize fights, held in movie houses, where the TV image is projected onto the large movie screen.

TV image projection systems are identical in the signal processing sections to standard TV receivers. The CRT, however, is a small, high-voltage unit designed to produce a very bright image which can be projected onto a large motion picture type screen by an optical projection system.

One system, known is the Schmidt system, is illustrated in Fig. 4-10. A high-intensity picture appears on the special CRT face. Light from the CRT is transmitted to a spherical mirror and reflected in the reverse direction through correcting lenses onto a screen.

Typical screen sizes can be from 6' X 8' to 15' X 20', with the screen located some 15-35 feet from the projector. About 50-150 viewers can view the screen in reasonable comfort. Picture quality inevitably suffers some degradation.

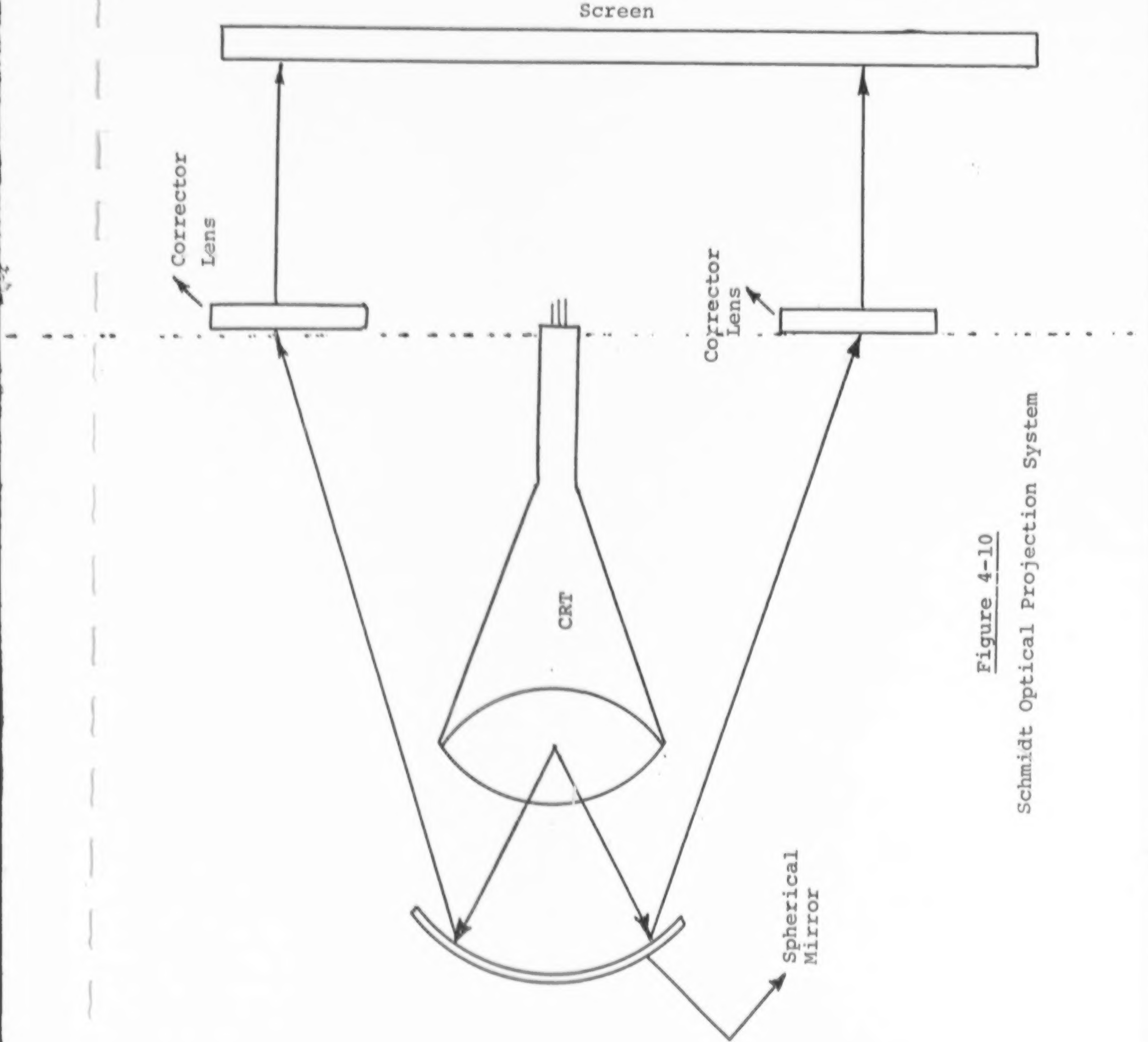

Screen
Corrector Lens
Corrector Lens
CRT
Spherical Mirror

Figure 4-10

Schmidt Optical Projection System

The cost for such a projection system is about $3,000 - $4,000. The system is considered useful where picture brilliancy, distortion and resolution can be sacrificed to some extent to the ability to serve more viewers.

4-4.a Video Recorder/Players

To date, the only method of storing and playing back video information directly without requiring intermediate media transformation, has been the use of video magnetic tape.

The video tape recorder/player was introduced to the TV broadcasting industry in 1965, and equipment in a wide range of sizes, capabilities and prices has become available since then.

The basic concept of the video tape recorder is identical to that of the audio recorder, namely, the conversion of the visual information into electrical currents and the use of these currents to structure the magnetic coating on a strip of tape. The key difference, however, (and a major one) is in the volume of information to be stored per unit of time. The audio recorder must store signals with a bandwidth of perhaps 20 KHz, while the video unit must store some 200 - 300 times that quantity.

Theoretically, this might be accomplished by "writing" on the same tape at a proportionally higher tape speed. The enormous tape speeds required, in the order of thousands of inches per second, makes this approach mechanically unfeasible.

The solution was a design in which both the magnetic head(s) and tape move at a high speed relative to each other. Four heads are equally spaced around a rotating wheel powered by an electric motor. The wheel brings each head transversely down the tape, while the tape itself is moving relatively slowly in a direction parallel to the axis of the head wheel. The tape motion is designed to be just fast enough so that each head can write one magnetic track traversely across the tape. (Actually the track is slightly skewed from the transverse due to the tape motion; by the time the head has reached the bottom of the tape, it has moved a little.) The next head on the wheel records another track adjacent to the first, and each quarter-revolution of the wheel therefore continues to record another track.

Because of the four heads, this type of recording is called "quadruplex". Quadruplex video recorders, using 2-inch wide tape, have become standardized for professional TV broadcast use. Although providing high-quality video storage, with no noticeable loss of visual information, they are expensive, running from $20,000 up to about $100,000 for a color unit.

More recently, a second recording technique termed "helical scan" or "slant-track" recording has been developed, permitting the manufacture of smaller, lower-cost video tape recorders, more suitable to educational budgets. The method of recording is somewhat similar to the principle long used in facsimile of combining rotary with linear motion to produce a helical scanning or recording pattern.

The magnetic tape is wrapped around a large scanning drum containing one or two magnetic heads which rotate on a high-speed disc inside the drum. The tape is moved just fast enough so that, in conjunction with the head movement, a series of tracks are recorded slant-wise across the tape. These are relatively long compared to the short, nearly-transverse tracks of the quadruplex recorder.

Usually the combination of tape width, number of heads, head speed and tape speed are chosen so that the time duration of one slant track is exactly equal to one (or some submultiple of a) TV frame. This makes the recorder more compatible with

with playback into a TV receiver. It also provides "stop-frame" amd "frame-grabbing" capability by, in essence, forming a reiterative playback of a single track.

Helical-scan recorders are available at modest prices, from below $1,000 to about $15,000. They come in a variety of tape widths (1/2-inch to 2 inches), tape speeds, reel sizes and performance characteristics.

The major problem with helical-scan recorders, unlike the more professional quadruplex units, is their lack of standardization. Not only can tapes from one manufacturer's recorder usually not be capable of playback by another manufacturer's unit, but it is not unusual to encounter this incompatibilicy between different recorders of the same manufacture and model.

This highly undesirable feature, not yet remedied, drastically limits the interchange of program tapes, and increases the cost of educational programming.

Not all helical-scan recorders are acceptable for broadcast applications, since the FCC sets technical standards which these units may not meet. No such standards are in force for closed-circuit, cable or other non-broadcast use.

Costs for the blank, unrecorded magnetic tape range from $20-$30 for a 1/2-hour, 1/2-inch size to several hundred dollars for the 2-inch wide professional quality reel.

4-4.b "Home" Video Recorder/Players

The video recorder/players described in 4-4.a can also, of course, be utilized at the receiving and viewing site. Because of their high cost, however, the primary component of interest to the user is the "home" unit.

Within the last two or three years, an exceptional degree of interest (and publicity) has been generated with respect to "home" video recorders, by which is meant:

(1) A relatively low-cost unit capable of playing back stored aural/visual material through a standard TV receiver, using the receiver screen as the display.

(2) A modular, easily handled package for the program material, permitting convenient use by the general public (e.g., the reel threading and handling requirements of a professional video tape recorder would not qualify). Currently, the modules either in use or under development include cartridges, cassettes and discs.

In some cases, the home unit also can record material, such as an off-the-air TV program recorded electrically through signals taken from within the TV receiver, or optically with the addition of a video camera. The recording function, however, generally is subsidiary to that of playback, which permits access to prerecorded programs from a wide variety of sources, and allows the viewer to select the desired subject material from available "libraries".

If the home video recorder/player and, even more importantly, the program modules, can be priced attractively, presumably the entire U.S. population is opened as a potential market for buying or renting A/V program modules, in much the same way as it currently buys audio discs and tapes. Educational applications are a particularly interesting portion of this market, since the requirement for wired or broadcast networks could be eliminated in many cases, and the programs delivered directly to the end-user. As an example, correspondence school courses might naturally use A/V cartridges rather than the printed texts currently utilized to teach students.

Because of this vast potential, a number of companies are developing home video devices. Announcement of equipment characteristics and prices have been plentiful, but no mass consumer sales have yet occurred.

Not only are many companies developing products, but unfortunately, the technical approaches of the major competitors are different, and incompatible with each other. This is reminiscent of past compatibility problems in color TV, and the 33-1/3 vs. 45 rpm battle in phonograph records. Even where the technical approach is the same, such as in video tape recording, there is no accepted standard among manufacturers with respect to critical features such as tape width, cassette/cartridge size and type, performance characteristics, etc.

This lack of standardization acts as a barrier to user acceptance. Together with the fact that development is still in process for most announced systems, the result is that home video recorders remain a future, rather than a present, educational tool, although undoubtedly one of great significance.

Currently five technical approaches are vying for a portion of the mass A/V market. These include:

(1) Video Tape Recording (VTR)
(2) Electronic Video Recording (EVR)
(3) Selectavision
(4) Video Disc Recording
(5) Film-to-TV Conversion

A brief description of each of these approaches is provided below. Tables 4-4 and 4-5 list, comparatively, the key features and relative advantages and disadvantages of each system. It should be noted that in many cases the data are based on manufacturers' future estimates rather than on equipment now in production.

4-4.b.1 Video Tape Recording (VTR)

This approach retains video magnetic tape as the basic storage/playback medium, and is therefore similar in concept to professional and institutional applications now in use.

	Video Tape	EVR	Selectavision	Video Disc (Teldec)	8MM Film
	(Note - Exact features depend on specific mfr/model)				
Developed by	Ampex, Sony, Panasonic, Avco, others	CBS Laboratories	RCA	Telefunken/Decca	Nordemende, Vidicord
Licenses (if any)	Avco (Admiral)	Motorola, others in Europe, Far East	--	--	--
Equipment Cost:					
Playback - Monochrome	$350-800 *			$150 (monochrome)*	$850-900
" - Color	$800-1200 * ($100-200 more with recording capability) *	$795 (ind./ed. model) $350-400 (consumer model) *	$400 *	$250 (with auto. changer) * $350 (color) *	$850-900 *
Recording Capability	Yes	No	No	No	No
Program Cost - Blanks	Blanks - $10-20 *	--	--	--	--
Prerecorded - Color	$25 (60 min. color) *	$25 (25 min. color)(x)	$10 (30 min. color) * (x)		$40-50 (30 min. color)
" - Monochrome		$15 (30 min. monochrome)		$-2-3 *	
" - Qty. Discount		(x) $18.50 in 2,000 qty.	(x) $2-3 in 2,000 qty *		
Max. Program Length	30-100 min.	50 min. - monochrome 25 min. - color		12 min. (12" disc) 5 min. (9" disc)	30-90 min.
Performance Features:					
Stop Action/Single Frame Display	Yes	Yes	Yes	Yes	Yes
Specific Frame Selection	No	Yes		Yes	Yes
Slow Motion/Reverse Motion	Yes	No	Yes		No
Estimated Life of Program Module	200 plays	500 plays	Very high (indefinite) *	1000 plays *	200 plays
Video Horizontal Resolution	240-300 lines	at least 500 lines			
Bandwidth		4MHz		3MHz *	3MHz
Size of Player	Varies with mfr/model	20"W x 18"D x 8"H			
Weight of Player	15-40 lb.	40 lb.			

Table 4-4

Cartridge/Cassette/Disc Video Recorders

* - estimate only, not yet available

	Video Tape	Electronic Video Recording	Selectavision	Video Disc	8MM Film
Major Advantages	(1) Provides recording as well as playback capability (2) Erasable/reusable medium (3) Fair-to-good picture quality	(1) Provides safeguards against piracy (unauthorized reproduction) (2) Very good picture quality (3) Provides frame-by frame selection so that alphanumeric/graphic material can be studied	(1) Uses very inexpensive plastic for recording medium (10% of tape, EVR) (2) Holographic image technique provides high protection to dust, scratches, wear (3) Provides safeguards against piracy	(1) Uses inexpensive plastic disc (2) Provides safeguards against piracy	(1) Film provides high image storage density and good resolution
Major Disadvantages	(1) Duplication (dubbing) from master is relatively time-consuming at present (2) Provides no protection against unauthorized reproduction (piracy) of cassette program material (3) Relatively high equipment & program cost (4) No standardization among VTR manufacturers (5) Many replays will degrade tape	(1) Provides no recording capability (2) High equipment & program costs (particularly where the program qty. is small)	(1) Still in development, first units expected in 1972 (2) Provides no recording capability	(1) Still in development, first units expected in 1972 (2) Provides no recording capability (3) Short program length per record; long programs require stacks of records	(1) 8MM film-to-home-TV-receiver equipment still in development, first units in 1972 (2) Recording capability requires camera, film processing equipment

Table 4-5

Cartridge/Cassette/Disc Video Recorders

The recording playback equipment, however, and to some extent the tape itself, are miniaturized and designed for a cost low enough to be attractive to the mass consumer market.

Ampex, Sony, Panasonic and Avco (Cartrivision subsidiary) have, among others, announced both recorder/players and cartridge or cassette modules for this market. As noted above, the products of these companies are not designed to common standards, so that a cassette for one system cannot be played back through another. Consequently, the first column of Table 4-4 represents a range of values covering the spectrum of all manufacturers' products.

Video tape recording is unique among the five approaches listed in permitting convenient home recording as well as playback. Naturally, the manufacturers of video tape equipment stress this advantage, as well as the erasibility and reusability of the tape. Proponents of other approaches not only downgrade the need for recording by the user, but point out that this very quality permits unauthorized reproduction and piracy of copyrighted program material, of the type now plaguing the audio disc and tape industry.

Figure 4-11 illustrates all of the steps required to produce mass quantities of prerecorded tape and replay them through the home TV receiver. The original A/V material, whether live, on film or video tape (probably non-compatible), is scanned and recorded on a video tape "master", designed to resist wear during the process of "dubbing", i.e., producing duplicates from the master.

At present, dubbing is relatively slow, increasing the cost of the prerecorded tape modules. Improvement in rapid duplication of multiple tapes is under development by a number of manufacturers.

Once duplicated and packaged into the appropriate cartridge or cassette, the program is made available through

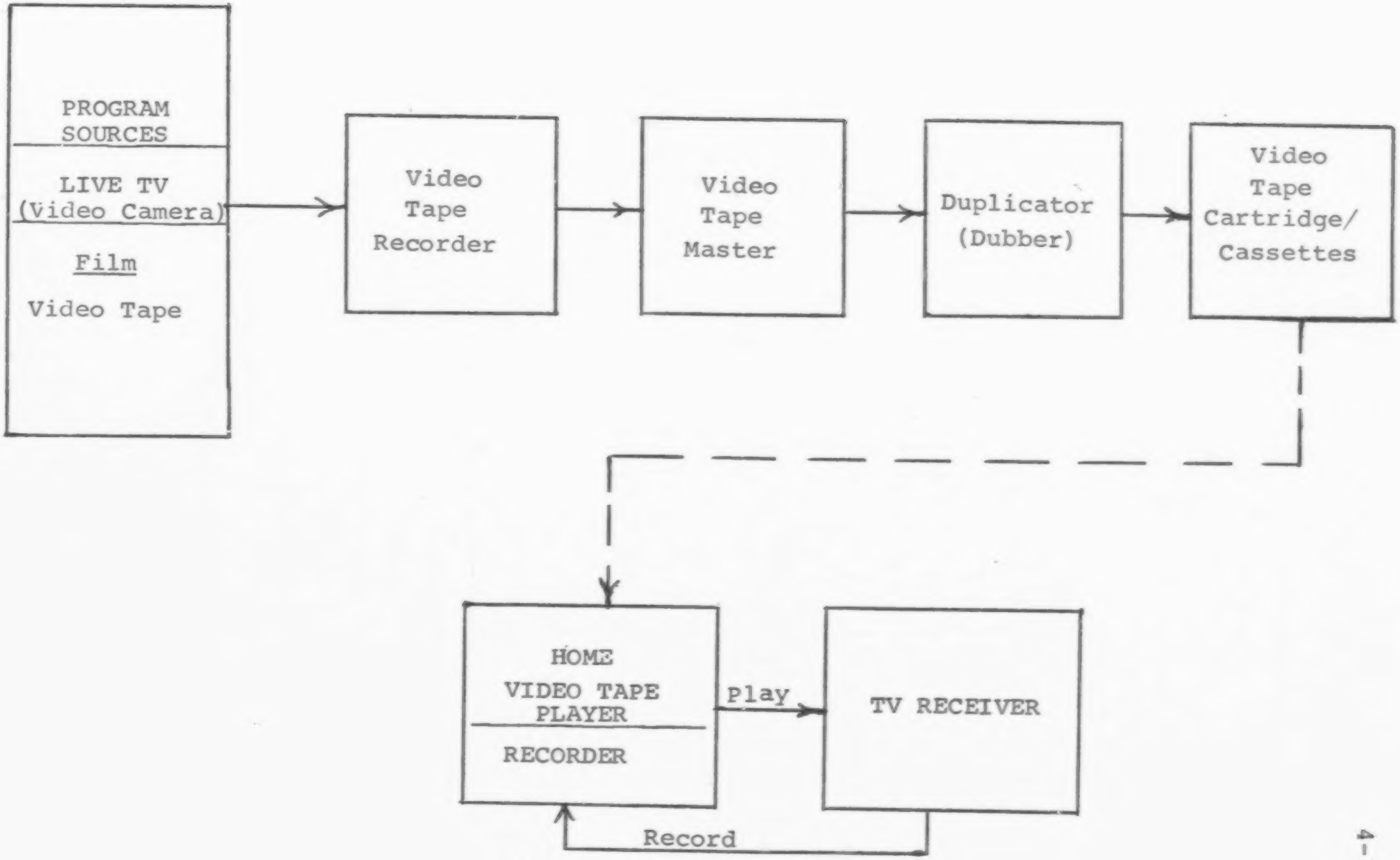

PROGRAM SOURCES
LIVE TV (Video Camera)
Film
Video Tape
Video Tape Recorder
Video Tape Master
Duplicator (Dubber)
Video Tape Cartridge/ Cassettes
HOME VIDEO TAPE PLAYER
RECORDER
Play
TV RECEIVER
Record

Figure 4- 11

VIDEO TAPE PROCESS

the normal distrubution outlets (plus, for educational applications, perhaps, new outlets such as schools and libraries) and can be played back at any location where there is a TV receiver.

Since Table 4-4 lists a composite of many VTR systems, it may be of interest to examine, more specifically, the characteristics of a single manufacturer's VTR equipment. For this purpose, Ampex's "Instavideo" unit was selected, since Ampex claims this to be the smallest cartridge-loading video system in existence.

Table 4-6 provides the major Instavideo features, extracted from Ampex specification data.

4-4.b.2 Electronic Video Recording (EVR)

Of the five systems described, the Electronic Video Recording (EVR) process, developed by CBS Laboratories, is the first to market, having delivered playback equipment to institutional users within the last year.

EVR uses a combination of photographic and electronic techniques. The source information is converted into electrical signals by a scanning process (see Fig. 4-12), similar to that of broadcast TV or video tape recording, but in this case the signals vary the intensity of a beam of electrons within a vacuum chamber. The beam is formed by an "electron gun" not unlike that in the neck of a Cathode-Ray Tube. Instead of being focused on a CRT screen, however, the beam is moved over a special, high-resolution photographic film. The varying energy and the scanning motion of the beam combine to expose the film in a pattern analagous to the picture at the source.

The beam recording produces the "master" EVR negative. This negative is then used in conjunction with a high speed photographic contact printer to produce multiple positive copies, or "prints", on silver halide film, which are then packaged in cartridges.

Ampex "Instavideo" Specifications

Recorder/Player Size	11 1/8" x 13 5/8" x 4 5/8"
" " Weight	Less than 17 lbs. with batteries
Power	Battery-operated, rechargeable (Adapter for 12-volt auto supply)
Tape Cartridge	Uses 1/2" video tape Weight 6 1/2 oz. 4.6" diameter, 0.8" thick
Program Duration	30 minutes monochrome or color at Type 1 Standard (tape speed 7.5 ips)
Resolution	300 lines min. - monochrome 225 " " - color
Models Available & Cost	Prices (Estimated)*
(a) Monochrome; Playback only	$1,000
(b) Color; Playback only	$1,100 ($100 color board added to (a))
(c) Monochrome; Record and Playback	$1,100 ($100 record board added to (a))
(d) Color; Record and Playback	$1,200 ($100 record board added to (b))
(e) Camera (monochrome)	$550
Cartridge Cost	
Blank (low-moderate quantity)	$13
Prerecorded	No prices available; depends on cost of software preparation and expected size of audience

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*
(Note: Availability of sale to the institutional and consumer market estimated to be the 4th quarter of 1972)

Table 4-6

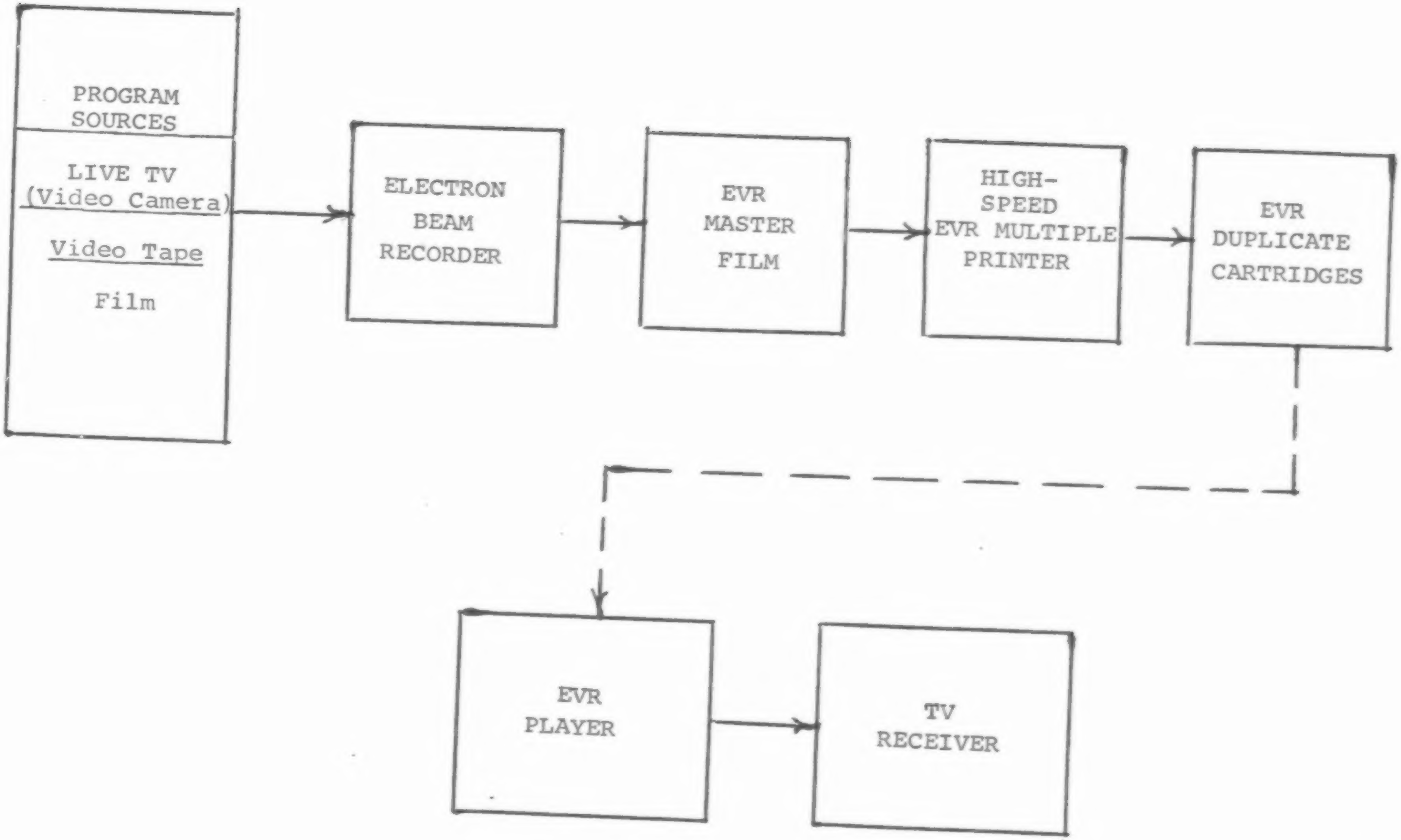

PROGRAM SOURCES
LIVE TV (Video Camera)
Video Tape
Film
ELECTRON BEAM RECORDER
EVR MASTER FILM
HIGH-SPEED EVR MULTIPLE PRINTER
EVR DUPLICATE CARTRIDGES
EVR PLAYER
TV RECEIVER

Figure 4-12

EVR PROCESS

The EVR cartridge film is dual-tracked, storing two adjacent rows of visual frames together with two parallel magnetic-stripe sound tracks. For monochrome programs, each visual track may carry independent information, resulting in a maximum playing time of 50 minutes for the standard 7-inch diameter EVR cartridge. For color, one visual frame carries "luminance" information while the adjacent frame carries coded color, or "chroma" information, so that only 25 minutes playing time is available from the same size cartridge.

Since information is stored on a frame-by-frame basis, as on motion picture film, and since also there are synchronizing signals stored, the EVR system lends itself to "selected frame" applications such as calling for pages from a book. This is particularly attractive for educational programs involving information storage and retrieval. The 180,000 individual frames (monochrome) stored on one EVR cartridge are, for example, equal to 600 volumes of 300 pages each, if one page can be legibly reproduced in a single frame.

CBS claims exceptionally good quality reproduction, due to the electron beam recording process. With a beam diameter in the order of 0.0001 inch, and very fine grain emulsion for the master, the resolution of the recording process, including the losses in duplicate printing, is claimed to be better than standard TV broadcast.

Because of the complex vacuum and electronic equipment necessary to produce an EVR master negative, no recording capability is possible at the playback site. "Software" or program production (i.e., prerecording on an EVR cartridge) is, therefore, strictly a factory operation. Indeed, for most educational applications, where it is impractical to set up a live production at the EVR factory, it may be necessary to record the program first on another medium, such as film or video tape, which is then sent to the EVR processing plant for transformation and duplication. This is somewhat awkward and costly, and, in addition, partially negates EVR's good reproduction qualities, since some degradation will take place during translation.

The EVR player unit contains a small CRT scanner which electronically scans the images on the film in the cartridge as it is moved past the scanning area. The scanning signal output is designed to resemble a TV video signal. This video output modulates an internal RF carrier set at any desired TV receiver channel frequency (probably a channel not assigned in that geographic area). Thus, the output from the EVR player resembles a broadcast TV program in every respect and can therefore be connected to the antenna terminals of any TV receiver.

Costs for the EVR player and prerecorded cartridges are, at this writing, relatively high for acceptance by a mass market. (The player costs about $800, with color programs averaging about $1 per minute). For this reason, initial sales are aimed at the institutional and educational markets. By 1972-73, the player cost is targeted to drop to perhaps $350-$400, at which time the consumer market may become predominant.

(Note: At the end of 1971, CBS announced that it was withdrawing from all manufacturing phases of the EVR market, concentrating only in software (program) production. Presumably the manufacturing of players and prerecorded cartridges would be licensed and taken over by others, but the accompanying indications that the video cassette market was developing more slowly than expected may make the above target dates optimistic.)

4-4.b.3 Selectavision

Selectavision is the trade name given to the system under development by RCA, which, technologically, is the most radical, utilizing laser holography. The player unit is the first consumer product announced which will incorporate lasers.

Figure 4-13 illustrates the Selectavision process. The program material is scanned and recorded on conventional film by means of an electron beam recorder. This step, in principal at least, is similar to EVR, and produces a master for subsequent duplication.

The RCA duplication process, however, is completely different. The developed master film is converted by a laser to a series of holograms recorded on a plastic tape coated with a photo-resist material which hardens in varying degrees proportional to the intensity of light striking it.

In the holographic technique, the visual image is recorded by splitting the laser light source into two beams, one of which is directed at the subject and reflected via mirrors onto the photographic film, and the other sent directly to the film. Because of the differing paths, there will be a slight displacement between the beams, forming an optical "interference" pattern (holograms) on the film. In concept, this is analagous to the "3-D" motion picture technique which utilizes two photographic images taken from different viewpoints and projected together to form a 3-dimensional illusion.

The photo-resist coated tape is developed in an etching chemical solution that eats away the portions not hardened by the laser beam. This results in a topographical "relief map" on the tape, whose hills and valleys represent the original images.

The tape is then nickel-coated, and the plastic subsequently stripped away, leaving a nickel tape with reverse, or "negative", impressions on it like a series of engravings. This is called the "nickel master".

The duplication process consists of feeding the nickel master through a set of heated pressure rollers, together with a transparent vinyl tape (similar to the kind used, for

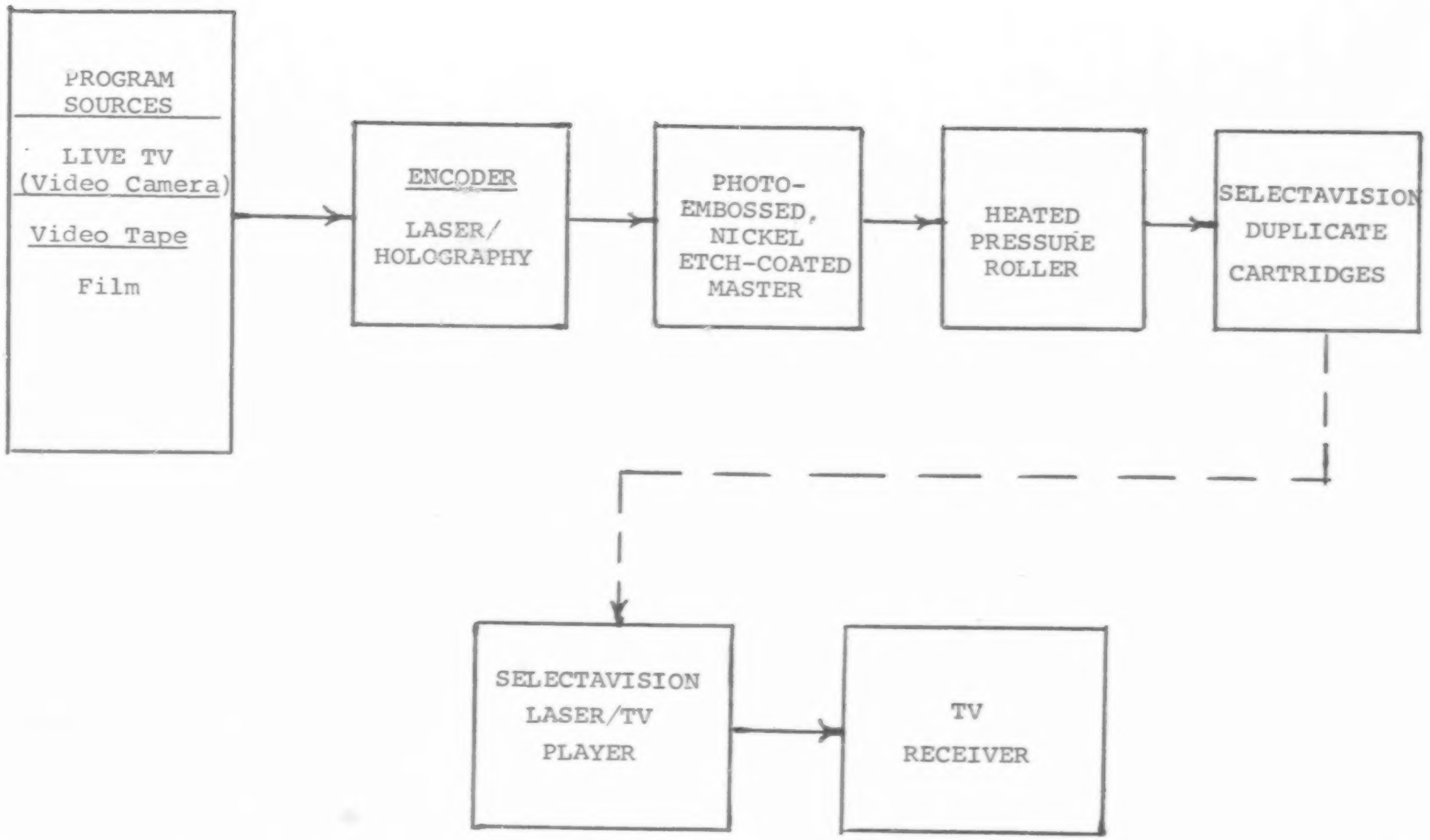

PROGRAM SOURCES
LIVE TV (Video Camera)
Video Tape
Film
ENCODER
LASER/ HOLOGRAPHY
PHOTO-EMBOSSED, NICKEL ETCH-COATED MASTER
HEATED PRESSURE ROLLER
SELECTAVISION DUPLICATE CARTRIDGES
SELECTAVISION LASER/TV PLAYER
TV RECEIVER

Figure 4-13

SELECTAVISION PROCESS

example, to wrap meats in a supermarket) of similar dimensions. The holographic engraving on the nickel master, due to the action of the pressure rollers, are embossed on the smooth surface of the vinyl, producing a duplicate "positive". This is then packaged in the Selectavision Cartridge.

This use of very low cost vinyl stock for the duplicates is a key feature of Selectavision. Estimates are that the cost of the raw vinyl would be about $0.06 for a half-hour cartridge. Furthermore, the nickel master can be used for thousands of "prints" without loss of quality, and the duplication time can be very short, since the embossing technique does not involve the time delay inherent in photographic, optical or magnetic response characteristics of various materials (as do EVR and video tape).

Thus, as shown in Table 4-4, RCA's present estimates are that prerecorded cartridges, in quantity, can be sold in the $2-3 range. If confirmed in practice, this is a great advantage of Selectavision.

Since the optical interference patterns of holograms require "coherent" light (extremely "pure" or, technically, single-frequency) to produce good resolution, and the most practical source of coherent light is the laser, this is why RCA uses the laser-holographic technique for recording. In general, the reverse is also true, that holograms require lasers to be read out. Thus, the Selectavision player also incorporates a laser for playback.

This is accomplished by passing the coherent beams from a low-powered laser in the player unit through the vinyl tape hologram. The image is reconstructed (with the two interference images superimposed back together) and projected to a Vidicon TV camera which scans and converts this image into an electrical form compatible with the TV receiver.

The properties of holograms are such that Selectavision claims further advantages. First, holograms contain all the information needed to reconstruct images throughout their structure. Thus, if the vinyl tape is slit to half its thickness, no picture content will be lost. This property, at least in theory, makes the tape relatively immune to scratches, wear and tear, etc.

Secondly, as the holographic pattern on the tape is scanned, the image projected from one hologram fades out as that of the next hologram fades in. This overlap and superimposition takes place regardless of the position of the tape, so that there is no need for synchronism between the tape motion and the camera scanning rate. This permits motion at any speed, slow motion, and single-frame stop-action.

In summary, RCA claims for Selectavision very low program cost, excellent wear characteristics and flexibility of viewing mode. These are significant features, but the proof awaits volume production of Selectavision players and cartridges, currently estimated for 1972-73.

4-4.b.4 Video Disc

The development of a video disc, similar in many respects to the present audio version, is currently under way in Europe through a joint effort of Telefunken and British Decca (TelDec). Production versions of players and discs are targeted for the European market by 1972.

The TelDec video disc is made of thin plastic foil, and is designed to deliver a picture to a TV receiver screen with a horizontal resolution of 250 lines. This is slightly inferior to standard TV broadcast quality.

A new method of recording grooves and ridges on the disc has been developed, in order to achieve the 200-fold increase in storage of information necessary for video images. Correspondingly, a new type of "pick-up" is required in the playback unit, which translates the mechanical variations on the disk into electrical signals, The TelDec player utilizes a sensitive pressure transducer which does not ride in the groove walls, as in a phonograph, but senses the variations in the surface of the disc.

Rather than a turntable, the disc is driven by a central carrier in the player and rotates above a stationary plate at speeds of 1000-2000 rpm. A thin cushion of air is formed between the disc and the plate, which has the effect of stabilizing disc motion.

For each single revolution of the disc, the pick-up arm is mechanically coupled so that it moves over the surface of one groove. This corresponds to one picture frame, so that one 360° disc revolution permits presentation of one frame on the TV screen. Thus, for the U.S. broadcast standard of 30 TV frames per second, the disc would revolve at 30 revolutions per second, or 1800 rpm. Since each groove is a complete frame, stop-frame and random access frame selection are possible.

The anticipated advantages of the TelDec disc are low cost for the player and discs. Production prices, as shown in Table 4-4 are estimated at $150 for a one-disc monochrome player and in the order of $2-3 per disc.

A disadvantage is that the discs, as presently designed, do not offer much playing time. An 8-inch diameter disc provides about 5 minutes, and a 12-inch disc about 12 minutes, of program time. Longer programs can be provided by stacking discs in an automatic changer mechanism, similar to phonograph record players, but this feature is bound to draw adverse comment.

The initial TelDec demonstration models have been monochrome versions. Color models are expected by the time initial marketing takes place.

For short A/V programs, up to the 12-minute maximum, the anticipated low cost of player and discs may hold some attraction. As in EVR and Selectavision, "masters" must be prepared in a factory processing facility, which would tend to inhibit educational applications where local program preparation and short "turnaround" times are desirable.

4-4.b.5 Super 8 MM Film-to-Video

Super 8 MM film cartridges are not in themselves a competitor to home video recorders since they require a separate projector and screen, and normally do not operate through a TV receiver.

However, two European firms, Nordmende (Germany) and Vidicord (England), have developed film-to-TV converters that can play Super 8 MM movies through a standard TV set. These systems have been demonstrated in trade expositions in Europe but are not yet available for sale.

The Nordmende converter carries an estimated selling price of $850 (color), while the Vidicord unit is priced at $888 (monochrome). Cartridge costs are estimated at about $1.20 a minute.

The advantages of the film-to-TV conversion are somewhat problematical. The need for a darkened room is eliminated, which is helpful for note-taking and classroom discipline in an educational environment. Further, the conversion permits distribution of the TV signal to a number of remote receivers so that several classrooms, for example, can view the picture simultaneously. Whether these justify the purchase of a converter in the near-$1000 price range, particularly when playback can be accomplished more directly and with better resolution through an 8 MM projector, is difficult to determine.

Super 8 MM cartridges are not standardized and generally can be played back through only one manufacturer's projector. This added burden makes the acceptance of film-to-TV conversion equipment even more dubious.

4-4.b.6 Impact of Home Video Recorders on Education

The impact of the "home video recorder" upon education is difficult to assess. Certainly, instructional, training and educational programs in cassette/cartridge/disc form will be available, and probably in quantity starting in 1972-74. The audience which is interested can select material as desired, view (and review) it at home, and with convenience. How many will take advantage of the opportunity will depend on many factors (e.g. motivation, program quality, cost, etc.), but a substantial positive stimulus is a reasonable expectation.

For the mass consumer audience, the primary reason to purchase and use home video equipment will be, if past history is any indication, the desire to extend the available spectrum of entertainment. Educational applications, however, may be a large enough secondary motivation to be of significance, even on an informal, individualistic basis.

In terms of formal, institution-directed education, the home video recorder represents a more convenient and, possibly, less expensive method of distribution of A/V information. This is true because of the present availability of large numbers of TV receivers, and not because of any new educational techniques provided by the equipment. Thus, more flexible and cost-effective program distribution to a larger audience is probable, but it is difficult to perceive any "cassette revolution" in terms of educational methodology.

4-5 Signal Conditioning

Almost all of the comments on audio signal conditioning and modulation techniques (3-4.1 and 3-4.2) are also valid for video signals, and therefore, will not be repeated here. Since much wider bandwidths are encountered with video, however, equipment to perform the same functions is usually more complex and costly.

TV broadcasting utilizes AM for the video information and FM for the audio. The arguments in favor of FM are as pertinent to video as to audio, but the required bandwidth for each TV channel would be so great as to make the concept impractical.

4-6 Educational Applications

The audio and video components reviewed in Chapter 3 and this chapter can be combined in a myriad of ways for educational applications, limited only by the normal constraints of cost-effectiveness and the imagination of educational planners.

Six typical applications are illustrated in Figures 4-14 through 4-19. These are suggestive only, and in no way exhaust the list of possibilities.

(1) Educational/Instructional TV - Fig. 4-14 illustrates what is currently the most-utilized educational application of A/V telecommunications, namely, providing educational or instructional TV programs to distant locations. These may be broadcast over-the-air, or transmitted over cable networks.

(2) Reproduction of Program Material - Rather than transmit the educational program in electrical form, an alternative is to deliver a stored version of the program for playback is desired by the user. Figure 4-15 illustrates one such system, in which reproductions of prerecorded video tape are dubbed from one recorder to another. The dubbed tapes are then physically transported to the using site.

(3) Recording of Broadcast Material - Many broadcast or cable-cast programs are transmitted at a time not convenient for viewing by all users. With a video tape recorder, the program can be recorded for later playback (Fig 4-16). If the TV receiver does not have an output jack providing a video signal, a minor modification may be necessary to extract this signal.

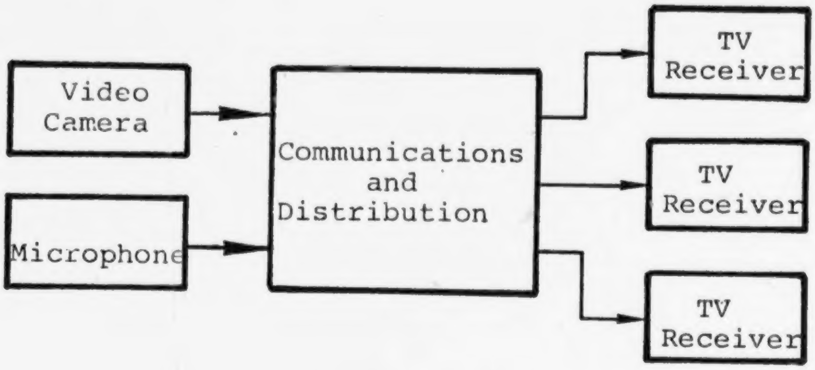

Video Camera
Microphone
Communications and Distribution
TV Receiver
TV Receiver
TV Receiver

Figure 4-14

Educational/Instructional Television

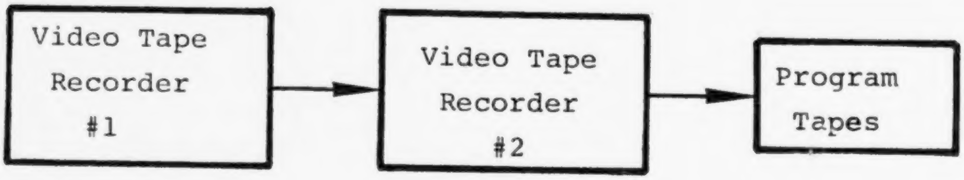

Video Tape Recorder #1
Video Tape Recorder #2
Program Tapes

Figure 4-15

Reproduction of Program Material

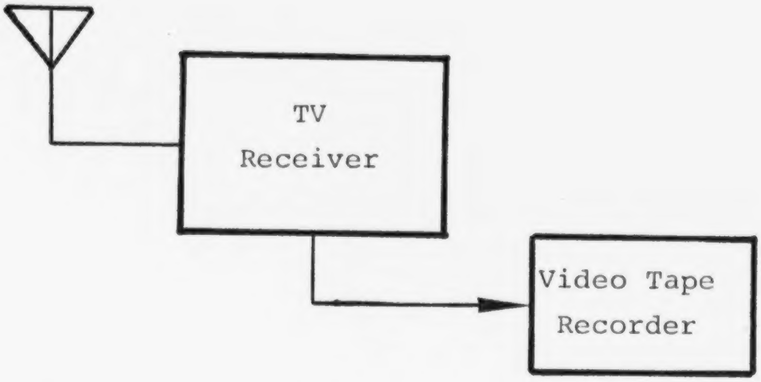

TV
Receiver
Video Tape
Recorder

Figure 4-16

Recording of Broadcast Material

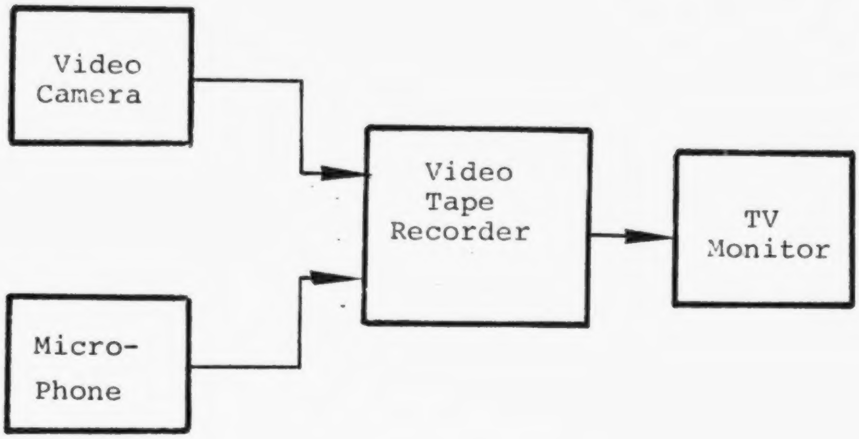

Video
Camera
Micro-
Phone
Video
Tape
Recorder
TV
Monitor

Figure 4-17

Instant-Playback of Live Material

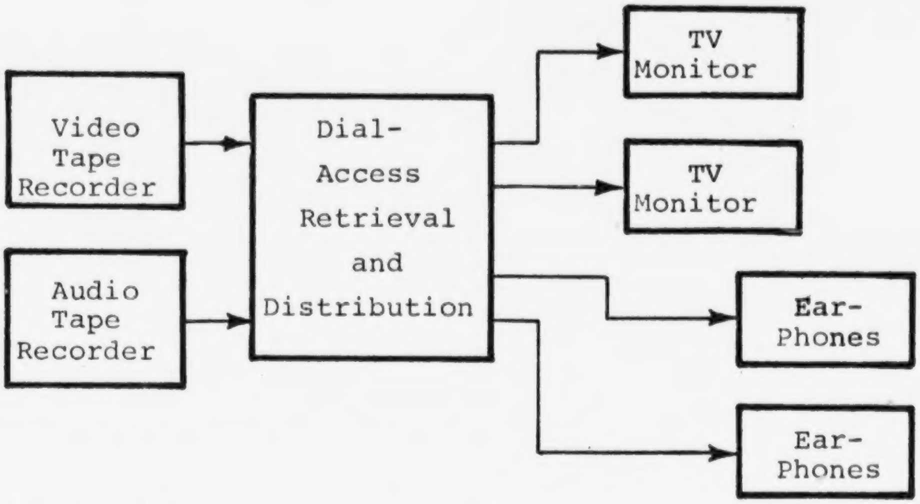

Video Tape Recorder
Audio Tape Recorder
Dial-Access Retrieval and Distribution
TV Monitor
TV Monitor
Ear-Phones
Ear-Phones

Figure 4-18
Audio/Visual Dial-Access Retrieval

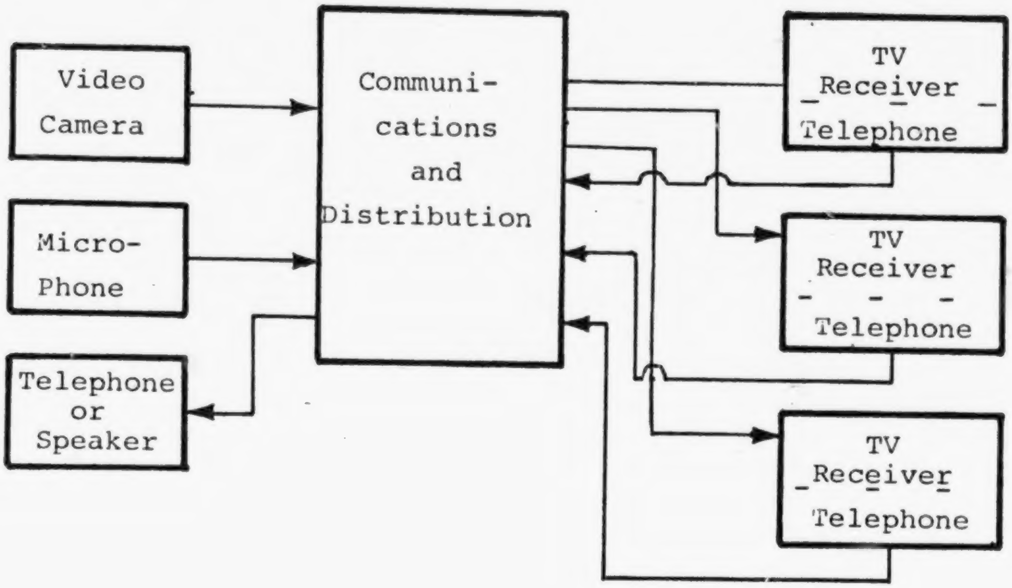

Video Camera
Micro-Phone
Telephone or Speaker
Communications and Distribution
TV Receiver Telephone
TV Receiver Telephone
TV Receiver Telephone

Figure 4-19
Educational/Instructional Television
With Telephone Query/Response Capability

(4) Instant Playback of Live Material - Many educational subjects such as drama, public speaking, gymnastics, etc., can benefit greatly if the pupil can see his or her own performance, rather than having it described by others. Video taping and immediate playback offer this capability, as illustrated in Fig. 4-17.

(5) Audio/Visual Dial Access Retrieval - Either video, audio, or combined A/V material can be recorded and stored in a manner permitting dial-access control and retrieval, and delivery of the retrieved information to any number of remote users (Fig. 4-18).

(6) Educational/Instructional Television with Telephone Query/Response Capability - Fig. 4-19 is an expanded version of the one-way system of 4-14, adding the capability of each viewer being able to ask questions of the instructor or comment on the program. This converts a passive educational technique into an interactive one, more nearly simulating the classroom environment.

Chapter 11 describes a number of integrated educational telecommunications systems, actually in operation, which perform the above functions, and others. It is important to emphasize again, however, that many other combinations of the available components and carriers are possible and warrant investigation. The technology in certain areas is, in addition, advancing rapidly so that concepts previously considered and abandoned may soon be both technically and economically feasible.

CHAPTER 4-BIBLIOGRAPHY

1. "Cartridge Television", industry report, Billboard, Sept. 26, 1970.

2. "Portable Video Tape Recorder: A Guide for Teachers", Stock No. 071-02514, Division of Educational Technology, National Education Association, Wash., D.C.

3. "Television Cartridge and Disc Systems: What Are They Good For?", February 1971, National Association of Educational Broadcasters, Wash., D.C.

4. "The Cartridge Revolution", special supplement, Cinema, Vol. 6, No.1.

5. "Video Tape Recorders for Institutional Use", Booklet #5, Maryland Center for Public Broadcasting, Owings Mills, Md. McAdam, J. Robert, and Vento, Charles J.

6. Witherspoon, J.P., and Kessler, W.J., "Instructional Television Facilities: A Planning Guide", Report OE-34043, Office of Education, under Contract No. OEC-1-7-071021-4429, U.S. Dept. of Health, Education and Welfare, 1969

Chapter 5 - Hard Copy

Many telecommunications systems, educational or otherwise require a permanent record, in printed or graphical form, of the information being received. This type of record, usually on paper, is termed "hard copy" to distinguish it from the "soft" (non-permanent) records such as the display on a TV receiver screen.

Examples of hard copy are alphanumeric messages, maps, illustrations, graphs, photographs or hybrid combinations of any of these. Physically, hard copy may be produced on standard sheets, continuous tear-off rolls, fan-fold print-out forms or in a format designed especially for a specific hard copy terminal. The only common element is that a permanent record suitable for visual interpretation be the end-item.

Two categories of hard copy devices, which include almost all possible applications, are considered. The first is limited to reproduction of alphanumeric (and some symbolic) characters only, essentially the equivalent of text material. The second is more comprehensive, being capable of hard copy reproduction of graphical and photographic material in addition to alphanumeric. For this reason, the latter can be termed "full-range" hard copy terminals since almost any visual image at the sending end can be reproduced at the receiving site.

The devices described below are "terminals" of a larger system rather than stand-alone units in that they are activated by electrical signals emanating from the system. Thus, a typewriter whose keys are actuated by incoming electrical signals falls into this category, whereas the same typewriter actuated by a human operator is not considered a telecommunications device.

5-1 Alphanumeric Terminals

The telegraph, as the pioneer application of telecommunications to the transmission of alphanumeric information, is still the conceptual model from which modern data communications and hard copy alphanumeric printout have evolved. As such, a brief review of telegraphic techniques is warranted as background.

A telegraph system, like the more general telecommunications system, includes the information source, the transmission and distribution network, and the receiving terminal(s). Specifically, the following actions take place:

(1) At the information source, the alphanumerics are converted into electrical signals with an agreed-upon code for each letter, number and symbol. Since there is a discrete number of alphanumerics, there will be a discrete number of codes which represent all of the information that can be transmitted.

(2) The coded signals are sent through the system, together with synchronization information (start/stop or Mark/Space) that allows the receiver to keep track of the incoming message.

(3) At the receiving terminal, the code signals are converted back into printed alphanumerics.

Before the advent of keyboard devices such as the teletypewriter, the telegraph operator used a simple "sending key" to perform manually the alphanumeric-into-electrical translation. The key consisted of a pair of electrical contacts normally held open by a spring. When the knob on a contact lever on the key is depressed, the contacts close, permitting current to flow in an electrical circuit. Thus, the operator can interrupt the current flow in accordance with the pattern of key depressions.

The code long used in telegraphy for transmitting information is the famous Morse Code (still utilized). This represents each letter or number by a combination of "dots" and "dashes". The dots correspond to short pulses of current resulting from the telegraph operator depressing the key for a short time for each dot, and the dashes to longer key depression and current pulses.

With this technique, the skill of the manual operator was a major factor in the system, and also a limitation in terms of achievable transmission speed. The development of the teletypewriter increased transmission speeds and decreased errors, but was still subject to operator limitations. Still later, the introduction of punched-paper tape and magnetic tape control of data transmission effectively removed this bottleneck.

5-1.1 Teletype Conversion of Alphanumeric Information

When the keyboard-operated teletypewriter supplanted the sending key in telegraphy, it laid the foundation for most data communications techniques and components. Its operation, described below, can therefore be considered a prototype of many current printout devices.

Each key of the teletypewriter, when depressed, closes a group of switches, which corresponds to a specific electrical code assigned to that character.

A variety of codes can be used. Early equipment used only five switches, allowing a total of only 32 combinations. Since this is insufficient to transmit even the minimum of 26 letters (A-Z) and 10 numbers (0-9), a coding "trick" was used in which, if a special upper/lower case key were depressed, each code could represent one of two characters. Thus, up to 64 characters could be transmitted.

More modern codes range up to 9 elements per character, allowing special symbols to be sent and providing error checking capability.

One possible method of transmission is to send each code element of a character simultaneously over a separate line (parallel transmission). This simplifies the electronic circuitry but requires, for example, 7 wires for a 7-element code. This may be acceptable, and even desirable, for short transmission distances but is too expensive for long-haul transmission.

The alternative is serial transmission on a single line, and this is the technique used almost universally today.

In the serial mode, the keyboard switches connect to a device that resembles an automobile distributor. When a key is depressed, the rotor mechanism starts up to encode the character, making one complete revolution at a fixed speed to sense all switch settings. As the rotor passes the segment for a given switch, a pulse is transmitted over the communications line. (See Figure 5-1)

At the receiving end, a similar rotor mechanism converts the serial pulses back to parallel ones as the rotor passes each receiving switch position.

The receiving rotor must be kept in step with the sending rotor to set the switches properly. Since the rotor mechanism of the receiving unit makes a revolution only when a character is to come in, the problem is solved by sending a "start" pulse before the transmission of the serialized character. This pulse also starts the rotor in the receiver. Mechanical governors keep the receiving rotor in step with the sending rotor.

Occasionally spurious signals enter the line from such things as lightning storms or line shorts, and throw the two teleprinters out of synchronism. To resolve this problem, one or more "stop" pulses are transmitted to reset the mechanism at the end of each character.

Thus, each transmitted character is a complete packet of information containing start, information, and stop pulses - a scheme known as asynchronous transmission. The characters may be sent continuously or with large gaps of time between them.

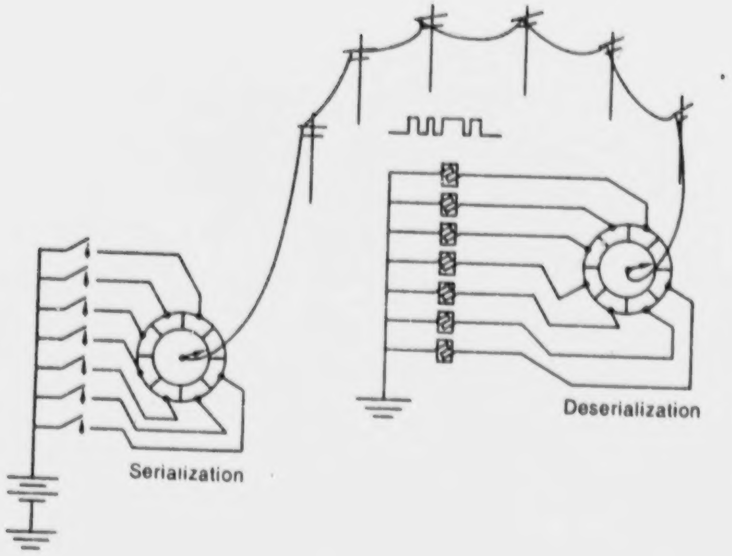

Serialization
Deserialization

Figure 5-1

Teletypewriter Serialization of Alphanumeric Data

At the receiving teletypewriter terminal, the switch settings established by the rotor are used to select a particular solenoid (electro-mechanical actuator) which is associated with the key corresponding to the code just transmitted. The solenoid is energized, pulls down the key, and the key striking the paper produces the character.

5-1.2 Teleprinters

"Teleprinter" is the generic term for interactive electrically-actuated printing devices which also incorporate a keyboard, including as one major category the teletypewriter described above. In addition to hard copy, some units can also provide a coded perforated paper tape or magnetic tape which records the same information printed.

The interactive send-receive capability, the simple keyboard input and the low/medium printing rates make the teleprinter most compatible with educational applications of the query-response type, and accordingly this class of printers is encountered most often. When more retrieval systems come into operation, placing a premium on higher printing speeds, the faster types of printers, such as the line printers discussed below, will be utilized to a greater extent.

Teleprinters can be characterized in several different ways:

(a) their maximum printing speed
(b) the printing technique used
(c) the capability to interface with communications, computer or other terminal equipment
(d) their cost, size and/or degree of portability
(e) the code(s) used for data communications

Since a keyboard is used to send information, the data input rate usually will be comparable to that of a good typist, in the order of 10 characters per second. This, in the past, determined the data output (printing) rate too. More recently, however, it has been an increasingly common practice to store the data on tape, as it is being typed, and play it back into the communications system at a higher speed, to take advantage of the maximum transmission capability of the communications link.

With this technique, it is desirable to have the receiving printer able to match the higher rate. Consequently, many modern teleprinters can print at speeds up to 30 or more characters per second.

Almost all teleprinters, either in their standard model or with modifications, can interface with a computer or another teleprinter, either directly or through a communications link. In fact, virtually every computer time-sharing system features teleprinters as the major remote terminals.

One significant recent advance has been the standardization of code and electrical charactistics. Although a variety of character coding schemes are still used, many equipment manufacturers have accepted the USACII (U.S.A. Standard Code for Information Interchange) code for general use. USACII is an 8-level, 128-character code standardized by the federal government for its internal data communications.

The electrical interface characteristics between a terminal and a communications channel have also been standardized by Electronic Industries Association (EIA) Standard RS-232. This defines features such as pulse widths, rise times, etc. for equipment designers.

Printing techniques are either of the impact or non-impact type. The impact type is similar to a typewriter mechanism in which, as each character is selected, a typing bar or other moving element strikes the paper through a ribbon or inking device. Speeds of impact teleprinters are limited to 10-15 characters per second, and costs are in the $600-3,000 range. Carbon copies can be produced as desired.

Non-impact techniques include "ink-jet squirting" and electrostatic or electrographic transfer. Examples of the ink-jet type are the Teletype Corp. "Inktronic" and A.B. Dick Company's "Videojet" printers. The Inktronic uses 40 stationary nozzles through which ink is electrostatically drawn and simultaneously charged. The charged ink stream is squirted onto the paper, writing one character at a time. Each character is actually written as a series of dots of ink which, blending together, give the appearance of a continuous line. Up to 120 characters per second can be printed. The Videojet is even faster, capable of 250 characters per second, which is equivalent to the data capacity of a voice-grade telephone circuit.

The cost of an ink-jet type teleprinter is in the $5,000-$7,000 range, restricting their use to medium/high speed applications.

The electrostatic/electrographic printers are also capable of higher speed than the impact type. They use a stationary matrix of wire stylii (essentially metal needles) under which the paper moves. Electrical current is sent to only those stylii needed to form a character. If the process is electrostatic, each stylus which is energized will charge a small area of paper, while in the thermal electrographic process, the stylus slightly burns the paper area. In either case, the paper moves on through a chemical "toner" both, after which the imprinted characters appear more clearly.

Costs for the electrostatic/electrographic printers approximate the ink-jet type, and even higher printing rates are possible.

A disadvantage of both the ink-jet and stylus printers is that only one copy is produced and carbons are not possible.

Of the hundreds of thousands of teleprinters in current use, the vast majority are Teletype Corp. units, partly because of their utilization for many years in telegraphy and partly because of their relatively low cost and adequate reliability.

The older Teletype units most often encountered are the Models 33 and 35. The Model 33 is designed to send and print only numbers (at a maximum 10 per second rate), with a few letter keys as control symbols. It is, therefore, primarily for data processing and computation applications. The Model 33 is the lowest cost teleprinter, priced at $600-700 depending upon options.

The Model 35 has complete alphanumeric capability, with a keyboard almost identical to that of a typewriter. Its transmission and printing rate is the same as the Model 33, and its cost is in the $1,700 range.

A more recent unit, the Model 37, has a higher speed capability, up to 15 characters per second, and sells for about $2,450.

Dozens of other manufacturers and models are available, with typical product surveys referenced in the bibliography for this chapter.

Modern teleprinters feature solid-state electronic circuits replacing most of the mechanical operations for coding, etc., reducing the operating noise of the unit and improving reliability.

Before a selection can be made for any educational application, the system requirements must be defined in terms of:

(a) Interface to the communications system

(b) Printing speed (maximum)

(c) Need for duplicate copies

(d) Desired printout format (e.g., on pre-printed forms)

(e) Need for recording on magnetic or perforated tape

(f) Specific coding, if any

Once these have been determined, the choice can be narrowed down to a manageable number of printer models, and the normal selection factors of price, reliability, maintenance, etc. can come into play.

5.1.3 High Speed Printers

While teleprinters are used primarily in the interactive modes, such as human-to-human or human-to-computer, there is a category of printers, operating in the computer-to-hard copy mode, which calls for very high printing speed to match the output capability of the computer. The hard copy, although eventually viewed by humans, is viewed later after printing is complete. Thus, the printer does not have to be slowed down to human reading rates.

Most high speed computer-output printers are "line printers" in that complete lines, rather than individual characters, are printed simultaneously, at speeds of hundreds (in some cases, thousands) of lines per minute.

Printing a line at a time is accomplished by including a buffer storage in the printer which holds each character as it arrives until a line has been assembled. Then all characters are printed at once and the buffer emptied for the next line.

In pace with the high speeds are high costs, ranging from $5,000-100,000 each.

Line printers are usually "receive-only" devices having no keyboard or other sending capability. They too are of the impact or non-impact types described above, with the non-impact units preferred for silent operation and graphic flexibility, while the impact models are used where multiple copies are necessary.

Because of their restriction to high-volume computer-generated data applications, line printers have not been used significantly in educational systems to date. With the growth of retrieval systems in the future, such as library interchange of printed material, high-speed hard copy may become a more important requirement. Large systems in which the output is centralized at one or two locations could justify the cost of line printers. Until that time, however, business rather than educational systems will to continue to be the major user.

5-2 Full-Range Terminals

5-2.1 Plotters

Plotters can be defined as equipment that accepts electrical input signals and produces a permanent hard copy"picture". The picture may be any two-dimensional visual pattern.

Since facsimile recorders do the same thing, it may be helpful to describe the differences. Facsimile, described next, is a system in which the operation of the sending and receiving devices cannot be divorced from each other. The facsimile receiver/recorder, in fact, is synchronized always to be "in step" with the scanning process at the transmitter, and the picture is reproduced in the same pattern as scanned. A facsimile recorder, therefore, cannot function except as part of a paired set.

Plotters, on the other hand, can accept input signals from a variety of sources such as computers, measuring instruments, magnetic or paper tape readers, etc. They are "receive-only" devices, placing essentially no constraints on the information source.

Since many plotters can draw alphanumeric and symbolic characters as well as graphical material, certain models are sometimes termed "printer/plotters" to signify this full range capability. They are similar in principle to any other plotters, but their resolution is sufficiently small to permit characters to be shown clearly. For such applications as annotating or labeling maps and illustrations, this feature is important.

Plotters operate through the relative motion between a writing pen or stylus, and the paper. One basic type of plotter, which keeps the paper stationary and moves the pen, is shown in principle in Fig. 5-2.

The writing pen is driven simultaneously along the X-axis and Y-axis of the paper by two motors and drive mechanisms.

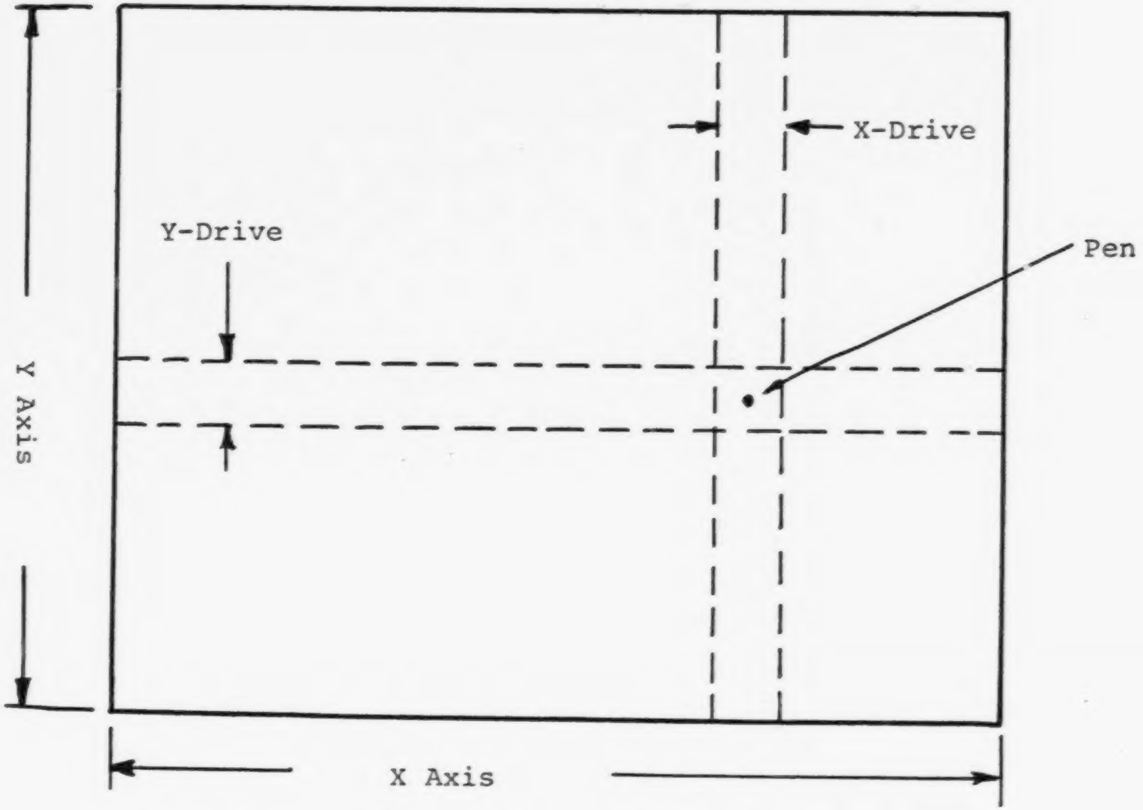

X-Drive
Y-Drive
Pen
Y Axis
X Axis

Figure 5-2

Principle of X-Y Pen Plotter

The X-drive, for example, is a vertically aligned track which moves left or right, and carries the pen along with it. Similarly, the Y-drive track moves up or down, again carrying the pen.

The distance either track moves depends on the magnitude of the electrical signal sent to the respective motors. If, for example, the plotter is designed so that an input of 10 volts to the X-motor will drive the track across the full width of the paper, an input of 5 volts will drive it to the middle.

The pen position, therefore, can be controlled in a predictable fashion by the electrical X and Y signals. One further item of information is required, i.e., when to print. Normally, the point of the pen is kept raised from the paper so that the pen will not smear while it is moving from one plot position to the other. A "plot command" lowers the pen so that a point is drawn at that instant.

Since the total picture is composed of dots, the plot resolution (like the photograph, TV picture or facsimile image) is determined by how small a dot can be drawn and how close the dots can be to each other. These key features, plus how fast the dots can be drawn, are the major factors that determine plotter cost.

A second plotting technique is to let the paper move so that in effort it replaces one axis drive. If the paper were wound on a cylindrical drum and unwound so that its motion were in the X-direction, then only a Y-axis drive would be necessary. This results in a simpler plotter mechanism, but the disadvantage is that the plot must be completed in one "pass" since the paper moves only once under the Y-axis drive. Some plots do not lend themselves to this technique.

A further refinement is the electrostatic/electrographic plotter/printer in which only the paper moves. The paper is revolved by a drum as before, moving past a row of stylii which extend from the bottom to the top of the Y-axis. Instead of physically moving a pen up and down, the appropriately located stylus is pulsed at the right time and a point drawn.

Another limitation of the drum plotter is that the drum speed is usually maintained constant. This is fine for graphs in which time is the X-coordinate, but restrictive for more general graphical material.

"Digital" plotters are those in which the input signals are in the form of numbers, rather than analog voltages. The plotter internal mechanism converts the numbers into positioning and plot commands. The ability to accept digital inputs makes the plotter a natural output device for computer-generated information, and in recent years many high-speed digital plotters have been designed to match a wide varity of computer applications.

The cost ranges for slow speed, X-Y pen plotters are from $500-2,500, while a fairly fast, high-resolution unit is in the $5,000 range. Computer-compatible digital plotters vary in cost from a low of $3,000-5,000 to upwards of $100,000.

Educational applications for plotters have been relatively rare to date, partly because of the equipment cost and partly due to a lack of definition of educational systems which might require a hard copy plot output.

5-2.2 Facsimile

Facsimile is the term given to the method of producing hard copy reproductions (facsimiles) of printed or graphic material at distances remote from the original by means of electro-optical scanning, telecommunications, and plotter/printer techniques. It differs from television in the following ways:

(a) The original material is motionless, fixed in position for scanning, and is usually limited to documents (letters, drawings, maps, photographs, etc.) where the key information is two-dimensional. For this reason, facsimile is also termed "graphic communications."

(b) While rapid reproduction is always desirable, it is usually not a critical parameter compared to reproduction quality or cost. Cost is dependent on transmission time, since common-carrier transmission facilities are generally utilized and paid for on a "time-utilized" basis (like a long-distance telephone call).

(c) The end product is a permanent (paper) copy serving, at the receiving end, the same function as the original would if it had been physically transported. Thus, not only the information content, but the format and record storage capability are important.

The scanning process in facsimile is similar in concept to that of television, using a line-dot pattern. In facsimile, however, the original material is scanned only once. Since it is motionless, a single scan will gather all the visual information.

A resolution of about 100 dots to the lineal inch is used in commericial facsimile equipment (10,000 per square inch). This is sufficient to reproduce text, drawings and continuous-tone images such as photographs with acceptable quality. For example, "wirephoto", a facsimile process, has been used for years to transmit newspaper photographs for subsequent printing.

The main problem with facsimile is the historical decision, made many years ago, that the common-carrier telephone/telegraph network would be the primary communications link for facsimile transmission. This was logical since the network was available, and the users of facsimile, mostly business and industrial firms, were not interested in financing special-purpose transmission systems.

Therefore, facsimile transmission was constrained to the data rates of voice-grade telephone lines with bandwidths of about 3 KHz. To see the effect of this, consider sending one page of material over a phone line via facsimile.

An 8-1/2" by 11" page covers an area of 80 square inches, assuming the contents lie within 8" by 10" borders. At 10,000 dots per square inch, the total facsimile message is 80 times 10,000, or 800,000 dots of black/white information which have been scanned in a predetermined sequence. If we make a crude approximation of equating each dot to the information content of one frequency cycle of alternating current (which a repetitive black/white pattern, alternating every dot, would approach), then the 800,000 dots would be the equivalent of 800,000 successive cycles.

When we take this number of cycles and transmit them over a 3 KHz telephone line, which can carry only a total of 3000 cycles each second, it obviously will take $\frac{800,000}{3,000}$, or 267, seconds to completely transmit the message. This is around four and one half minutes and is the approximate time required by facsimile systems. Most commercial equipment presently on the market requires from three to six minutes to reproduce one 8-1/2" by 11" page, while more recent and more expensive higher speed units require about one to two minutes.

It is evident that the only way to increase reproduction speed (assuming no degradation in quality, which means at least the same incremental resolution) is to increase the rate of scanning, which generates the dot sequence, and also the speed of transmission, which in turn means more dots transmitted per second. This leads away from the standard, voice-grade line to higher band-width communications links, and these indeed have been utilized. The cost, however, increases proportionally.

Furthermore, if the scanning rate is increased substantially, the present electromechanical scanning methods of facsimile equipment must be replaced by all-electronic techniques. In effect, a facsimile scanner becomes more like a video camera and facsimile transmission becomes more like slow-scan TV. The only difference remaining is the hard copy output of facsimile, and since this is also produced by electromechanical means, there is a definite limit to transmission speed which is imposed at the receiving site. This can be overcome by recording the incoming signal on tape, for example, and playing it back later at a slower rate into the facsimile recorder, but the system becomes cumbersome and expensive.

From the point of view of educational applications, there are certain advantages to facsimile:

(a) Both the original and final products are paper documents resembling items that normally are used to a major extent in education (e.g., textbooks, reports, diagrams, quizzes and test papers, etc.). Thus, if facsimile reproductions are used instead of originals, no psychological adjustments are necessary by teachers or students.

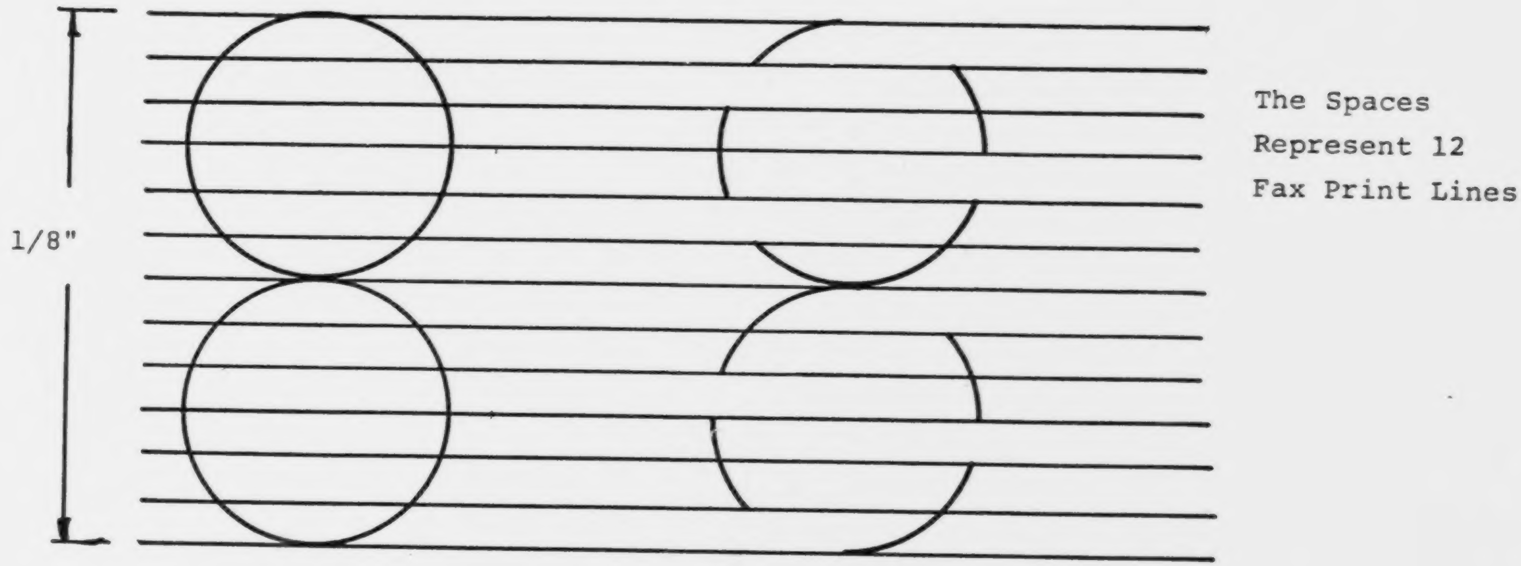
(b) Facsimile has a wide tolerance to communications transmission errors. Since any single image is made up of many dots, the loss or misplacement of a surprisingly large number will not generally prevent the human eye and brain from reconstituting the original. (See Fig. 5-3)

(c) Facsimile is inherently compatible with computer-controlled output information whether microfilm, graphical or alphanumeric, or more likely, combinations of these.

Until the present, these advantages have been overbalanced by the relatively poor speed and cost characteristics. Major improvements in the future can, however, expand facsimile's usage out of the business applications category into educational areas.

The technology of facsimile is relatively simple to understand, and comparison charts of available products are periodically published (see Bibliography) and updated.

A minimum facsimile system consists of one scanner/transmitter, one receiver/recorder and the communications link. If two-way send-receive capability is required, a "transceiver" combining the capability either to transmit or receive is used at each end.


1/8"
The Spaces
Represent 12
Fax Print Lines

The two characters illustrate that even with eight (8) parts of the character on the right missing. It is still as legible as the left one that printed all twelve (12) of the lines normally used in **1/8"** space at 96 lines per inch density.

Figure 5-3

Advantage of Fax Redundancy

Almost all current facsimile scanners use electromechanical scanning techniques in which relative motion in a predetermined sequence between the document to be reproduced and a photo-optical sensor produces a sequential output of pulse signals from the sensor. This is the so-called "flying spot" technique used in the past for CBS' proposed color television system (before standardization on the current electronic raster), and presently being utilized in at least one of the new "home video recorder" units.

The relative motion many be produced with the document remaining motionless and the photo-optical lamp/sensor head providing all of the scanning motion (flat bed technique), or the document wrapped around a rotating cylinder or drum, with the flying-spot sensor tracing a helical path which eventually scans all of the document area. Faster drum rotation speeds produce a more rapid scan. The key performance parameters are:

(a) Transmission Time. This ranges from about one to six minutes per 8-1/2" by 11" page, as previously noted, with standard phone lines.

(b) Scanning Density. The scanning density is a measure of the resolving power of the reproduction process. As noted, "100" means 100 resolvable increments to the lineal inch in any direction. Obviously, the greater the scanning density number, the more closely will the facsimile resemble the original. A density of around 80-100 has been found adequate to reproduce most text sizes, but it is important to realize that this assumes character sizes about 1/8" high or greater. For small type, 1/16" high for example, a density of about 160-200 is necessary. This doubling of the density per lineal inch would quadruple the information content per square inch and thus quadruple the total message length and, with the same line facilities, also the transmission time. This tradeoff always occurs, resolution (quality) versus time (and correspondingly, cost).

(c) Document Width. This is a constraint upon the original material to be reproduced. Although more a matter of standardization than of technology, the commercial manufacturers naturally have selected size standards meeting volume-market applications (e.g., 8-1/2" by 11" standard text page). Documents at the small and large size extremes may also be transmitted, the latter by sections at a time. Recent facsimile recorders use paper rolls rather than single sheets. This reduces labor at the receiving end, permitting longer periods of unattended operation.

Another point to note is that the density content of the original document has no bearing on the facsimile speed. Since a fixed scanning sequence is used, it takes as long to scan a page with only one word in the center as a page crammed full with text, diagrams, etc. Naturally, the first case is more wasteful of both scanning time and communications facilities.

Along these lines, newer systems are using "data compression" techniques similar to those employed in aerospace and computer data transmission systems. These generally involve "looking" at the electrical signals and detecting repetitive patterns which represent sizable patches of black or white on the document original. For transmission, only a transition from white to black or vice versa is communicated. The time interval between each transition also must be communicated by some scheme to the receiver to permit reconstitution. Thus, breaking the signal into two determining components, (1) period of time during which a black or white state continues and (2) location of transition points, permits sending all essential data, without transmitting repetitive signals which provide no new information.

Equipment is available which achieves one-minute transmission time over voice-grade lines for a 8-1/2" by 11" document, using such a data compression technique. A small special computer monitors the original scan, makes the compression decisions and translates the signals into an appropriate format.

A reduction of transmission time, using average toll charges of 20¢ per minute, will save 60¢ per transmission if three minutes are saved. Of more significance is the percentage decrease, 75% in going from four minutes to one minute per transmission.

These improvements have led to more widespread use of facsimile in recent years (see Chapter 11). In each case, the key factors which must justify its use are quality of picture, transmission time and cost, with any improvement in one factor usually at the expense of the others.

For a single two-way installation, i.e., one transceiver at each of two locations, the cost of medium speed equipment (3-6 minutes per page) will be about $5,000-$15,000, or an equivalent monthly rental charge of $100-300. It is important to note, however, that the phone line costs, depending on usage, can annually exceed the equipment costs.

5-2.3 Photographic Conversion

A seldom-considered alternative to producing a hard copy print or plot is simply to photograph a "soft" copy display, such as presented on a TV screen or CRT terminal. If the soft display is already available, the incremental cost of a still or motion picture camera is much less than that of a plotter.

Whether this method is acceptable depends on what kind of hard copy is desired, and also upon the quality of the image. If, for example, the hard copy is a page of text or a drawing which eventually will be microfilmed for permanent storage, then photographing directly would save time and money.

If, however, the hard copy pages will be bound in a book, the photographs must be enlarged and printed, and this procedure would appear wasteful.

Each time a media transformation takes place, some image degradation is inevitable. Thus, a film taken of a TV screen display will be inferior in picture quality to that viewed on the screen. These transformation losses must be taken into account to determine if the final result is acceptable.

5-3 Educational Applications

In theory, hard copy devices should find many applications in education, since what they produce is so similar to the kind of material that students conventionally use. The ability to transmit a map or engineering drawing to a remote classroom, in a form that the student can retain and mark up if he chooses, obviously is desirable.

The factors which, to date, have mitigated against such applications are cost, and also the relative infancy of planned systems which can efficiently utilize such terminals.

The cost factor includes not only equipment but communications charges which exist for all but in-house systems. Even the most elementary use of computer time-sharing systems, for example, requires a teleprinter terminal which carries a rental of $100-300 per month. If the terminal is used in a school classroom 8 hours a day, and the computer is far enough away to require phone line connection, the phone charges for that terminal alone can run $500-1,000 a month. If 100 students share the terminal, the cost per student per month is perhaps $10-15, which is a significant percentage of the school's total budget per student.

Nevertheless, interactive computer communications with hard copy printout is a part of a number of educational telecommunications systems now operating (see Chapter 12, for example), and can be expected to increase in the future.

This increase would be speeded up immeasurably if a low cost, educationally-oriented print/plot terminal were developed. Almost all terminals used today for education were designed as printouts for business or scientific use, and are not ideal for many instructional requirements. Students are using a Teletype (with all its noise and slow speed) to communicate with a computer simply because it is the cheapest marginally-adequate unit available, and certainly not because it is ideally suited to their needs.

The dearth of planned, organized and interactive educational telecommunications systems is also a problem. Hard copy terminals are what the name implies, terminal points of a system. The task of determining what to send a plotter, for example, and how to put it into the proper form are part of the system design.

Despite this, the trend is to an increase in the versatility of terminals, including plot/print flexibility, and it is to be expected that their use in educational telecommunications will rise sharply.

CHAPTER 5 - BIBLIOGRAPHY

1. "Facsimile Survey; Telecommunications, May 1971.
2. "Hard Copy Printers: The State of the Art", Telecommunications, December 1970.
3. Stiefel, M.L., "Digital Plotter Terminals & Systems", product profile, Modern Data, Sept. 1971.
4. Stiefel, M.L., and Murphy, J.A., "Teleprinters", product profile, Modern Data, May 1971.
5. Stiefel, M.L., "Printers", technology profile, Modern Data, February 1971 (Part I); March 1971 (Part II).

Chapter 6 - Computers

The pervasive role which computers have played in modern life needs no belaboring, and it is obvious that this role will continue to expand in the future. Applications which were theoretical concepts only a few years ago are now operational and thriving. Fox example, computer time-sharing has been available commercially only since 1965, and currently represents a market with annual revenues in excess of $100,000,000.

In education, the use of computers has been evolving somewhat more slowly than in other areas, partly due to the necessity to translate educational objectives into terms compatible with computer technology. Many projects have been initiated on a trial basis, with greater or lesser degrees of success, and some educational institutions have advanced to the point where computer-based instruction is an accepted portion of the curriculum. In general, however, the impact of computers on education in the U.S. is still preliminary and tentative.

Regardless of many valid arguments as to the appropriate relationship between instructor and computer, or the cost-effectiveness of computer education, it is clear that the computer's potential for augmenting the educational process is enormous, and that educational application will increase in the future. The eventual impact of computers on education may not reach the point of domination, as some computer proponents would forecast, but it will certainly affect in a major way everyone involved, educational administrators, teachers, students and the public.

6-1 Computer Fundamentals

Whenever the generic term "computer" is used today, it almost always refers to the electronic digital computer. There are computers which are not electronic (e.g., the abacus, the mechanical calculator), and there are also analog computers which handle information in continuous rather than discrete, digital form.

Analog computers, while still utilized in many process control and simulation applications, have largely given way to digital computers for general purpose use. The ability of a digital computer to be programmed by external instructions, and its greater precision, make it inherently a more flexible and powerful tool.

6-1.1 Basic Elements of a Computer

The basic elements of a digital computer are illustrated in Fig. 6-1. They include:

(a) Storage (Memory) Unit - This section stores information in electrical form, and provides means for accessing and changing that information. The information includes both the data of interest to the user and instructions as to how to process the data.

The memory stores its contents in the form of "computer words". A word can consist of a number of characters or digits (usually one to six), depending on the computer. A memory unit may be capable of storing from a few words to hundreds of thousands, equivalent to millions of characters.

Characters are coded and stored in the form of groups of binary digits ("bits"). A bit is a two-state electrical representation of either of only two possible digits in a numeration system with a base of 2. Usually, bits are represented as being in the "0" state or "1" state, and can be simulated electrically by two-state devices such as magnetic components, (magnetized to + or - polarity), switches (on or off), or bistable electronic circuits. The fact that only two states must be recognized greatly reduces circuit and equipment cost.

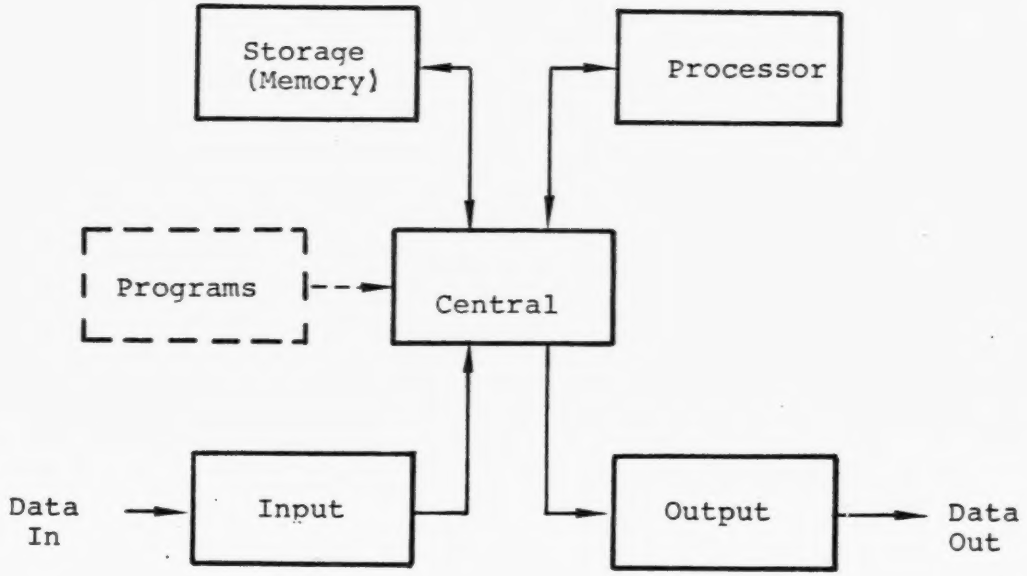

Storage
(Memory)
Processor
Programs
Central
Data
In
Input
Output
Data
Out

Figure 6-1

Elements of a Digital Computer

Combinations of "0" and "1" bits can be used in various coding schemes to represent any alphanumeric data. For example, two bits can provide four different combinations, "00", "01", "10" and "11", and therefore can be used to represent any four numbers or characters.

A binary code is one in which "1" bits are assigned values in a sequence of powers of 2, from right to left. Thus, in the binary number "101", the right-hand "1" is equivalent to 2^0 power or 1. The middle number is the 2^1 power number, and if it were a "1" bit would be equal to 2, but since it is a "0" it is equal to zero. The left hand "1" corresponds to the 2^2 digit, and would be equal to 4. The total number is the sum of the individual digit values, and for "101" would equal "4 + 0 + 1" or 5. Thus, the binary number "101" can represent the arithmetic character 5.

Table 6-1 shows how combinations of only six bits, in binary code form, can represent any digit, alphabetical letter, or symbol.

Thus, the memory section of the computer stores groups of bits in electrical or electromagnetic form. The bits in turn are coded to represent characters which may, if desired, be further grouped to form words. Subject only to the limitations of memory size and cost, any type of information can be stored and retrieved.

(b) Processor - This unit is the computational and data processing section of the computer. It must perform the minimal arithmetic functions of addition, subtraction, multiplication and division, and, depending on the size and complexity of the computer, usually can perform many more mathematical and manipulative operations.

Binary Code	Alphanumeric Equivalent
000000	0
000001	1
000010	2
000011	3
000100	4
000101	5
000110	6
000111	7
001000	8
001001	9
001010	A
001011	B
......	...
100011	Z
100100	+
100101	—
etc.	etc.

Table 6-1

6-Bit Binary Code Equivalents

Computers designed primarily for computation will have extensive processor sections which can complete thousands of arithmetic operations per second. Large, scientifically- oriented machines, (sometimes called "number crunchers") for example, may have an "add cycle time" (the time two numbers of word length can be added together) of one or two millionths of a second.

Computers used in information retrieval systems, on the other hand, are not required to perform much computation and will have limited capability in the respect. They will, however, feature highly efficient methods for accessing and moving large quantities of data, both internally and to external users of the system.

(c) Control - the control section is the "traffic director" of the computer, providing instructions to all components of the system as to what to do, and when to do it. The instructions originate from programs prepared previously.

Some functions exercised by the control section are:

(1) providing timing and synchronization signals
(2) directing the flow of data into and out of each section of the computer
(3) monitoring each operation to confirm that it has taken place
(4) checking for errors or omissions
(5) providing an interface to the human operators and/or users of the system

The control and processor sections in some computer systems are designed and constructed integrally, with the combined unit termed the "central processing unit" (CPU) or "main frame", including all computer equipment except memory, input and output

(d) Programs - Computer programs are the instructions which cause the computer to perform a desired sequence of operations. Programs are designed first as logical operational events which must take place, and then converted into appropriate electrical signals used to force the computer through these events. These signals, called "routines" and "instructions" are stored until needed for use, some within the computer memory itself and some on auxiliary equipment such as magnetic tape or discs which feed them into the computer when required.

The general classes of programs include:

(1) Operating Systems and Executive Programs - this category provides the basic instructions which are necessary regardless of the particular computer application. In effect, the operating system is the framework or structure which determines the path taken by each computer operation, the internal timing sequence and the integration of components. It can be likened to the engine of a car, which must provide certain capabilities regardless of which direction or how fast the driver wishes to go.

Operating systems are usually provided by the manufacturer of the computer. They may be modified or even replaced by user-created programs, but this requires expert knowledge on the part of the user.

(2) Applications Programs - these are the special-purpose instructions designed for particular applications of the computer. If the computer is to be used for education, for example, the programs which are prepared to allow the computer to accept and store educational

material, direct it to students, check and evaluate their responses, etc., would constitute a set of application programs. Using the same computer to prepare a payroll would require a completely different set.

Applications programs may be prepared either by the computer user or manufacturer, or both working in conjunction. The knowledge and objectives of the user are necessary in any event, since only the user knows in detail what the computer must do to perform as desired.

(3) Housekeeping Programs - these are programs designed to perform special tasks which are ancillary to the desired application, but still considered necessary. Diagnostic programs, which continuously check various points in the computer system to determine whether a malfunction has occurred, fall in this category.

Standard arithmetic procedures (e.g., extracting the square root of any number) or code conversion (changing decimal into binary) programs may also be included. These are referred to and used as needed.

Programs may be prepared or "written" in a variety of "languages". If they are prepared in terms which directly relate to the internal circuitry of the computer, it is termed "machine language". Machine language is most efficient, in terms of utilizing storage space and minimizing the computer time necessary to perform functions, but it requires such a detailed knowledge of the inner workings of the computer that its use is all but restricted to computer manufacturers or very skilled programmer specialists.

A variety of program languages, other than machine language, are currently in use, each requiring different degrees of computer familiarity to use. In each case, the programmer follows a prescribed set of rules in preparing his instructions and the computer converts these instructions to machine language internally.

Program languages which approach natural English are called "higher-order" languages. They require less computer knowledge from the person doing the programming, but more effort from the computer to make the necessary internal translation. Consequently, they are more suitable for teachers and students to use, but less efficient in taking advantage of maximum computer capability.

Nevertheless, the goal of higher-order languages, to allow the direct user to do his own programming, is so important, that considerable effort has been expended in this direction. In spite of the effort, however, natural languages are still many years away. Those which are relatively simple and in use currently, such as BASIC (Beginner's All-purpose Symbolic Instruction Code) are also limited in power and flexibility. More powerful standardized languages such as ALGOL (ALGOrithmic Language), FORTRAN (FORmula TRANslation) and COBOL (COmmon Business-Oriented Language) generally require programming skill.

Apart from the programs themselves, there is a variety of other non-hardware support items necessary for proper operation of the computer. These include manuals, information flow diagrams, and the documentation which defines and describes the programs. All of these items together are termed "software" as distinguished from the "hardware", i.e., the physical equipment.

An analogy to hardware/software might be a human being who, physically, would represent the hardware entity. His education, experiences and what he has acquired from his environment could be termed the software; they affect the way he functions.

(e) Input/Output - The input and output sections of the computer are its link to the outside world, and equipment in these categories is also called "peripheral equipment" to indicate that they function in the periphery between the computer and the various sources and users of data.

Table 6-2 lists the most common peripheral equipment items associated with computers. Almost any device which can store and/or communicate digital data can be used as a computer peripheral, although the cost and effort to achieve appropriate interface conditions may be quite extensive if the equipment was not designed originally for computer operation.

Many of the components listed are described in Chapters 3-5, and can be used in many educational applications which are not computer-based. Other items are useful only in conjunction with a computer, and are briefly reviewed below.

(1) Optical Character Reader (OCR) - a device which optically reads printed material and converts it into digital signals compatible with a computer. Many credit-card receipts, for example, are processed by OCR techniques.

(2) Punched Card Equipment - input/output devices used to read from or punch information onto a standardized 3-1/4" x 7-3/8" card, commonly called an "IBM Card".

(3) Perforated (or Punched) Paper Tape Equipment - input/output devices used to read from or punch information onto a 1"-wide sprocket-driven, paper tape.

Function	Type of Equipment
Input Only	Optical Character Reader Magnetic Tape Reader Punched Card Reader Punched Paper Tape Reader Magnetic Tape Reproducer Keyboard
Output Only	Printers Plotters Card Punch Paper Tape Punch Magnetic Tape Recorder Console and Terminal Display
Input/Output	Teleprinter Magnetic Tape Recorder/Reproducer Magnetic Disc File Magnetic Drum File Communications Modems and Data Sets Card Reader/Punch Paper Tape Reader/Punch Interactive Terminals

Table 6-2

Computer Peripheral Equipment

(4) Magnetic Disc File - a storage device, or auxiliary memory, which stores information on one, or a number of, magnetically-coated discs rotating at high speeds. Discs can be permanently fixed or removable (which permits interchange of storage files or programs on a modular basis).

(5) Magnetic Drum - a storage device, or auxiliary memory, which stores information on "tracks" of a magnetically-coated rotating drum. It serves the same purpose as a disc file, usually with somewhat longer data access times.

6-1.2 Operational Concepts

During the early and mid-1950's, the application of computer technology followed a growth curve so phenomenal that appellations such as "the second industrial revolution" became commonplace.

In most instances, the computer system was used in an "off-line" supportive function, (such as payroll preparation, for example). "Off-line" is characterized by:

(1) The computer and peripheral equipment generally are regarded as a semi-autonomous facility.

(2) Input data to the computer may originate from a single source or multiple sources, but in either case the original data usually is not compatible with computer input requirements. Transformation to punched cards, or perforated or magnetic tape, for example, is required before the computer can process the data. This transformation, in almost all cases, is performed within the computer facility.

(3) Input data are processed on a "batch" basis; i.e., a quantity of data, such as payroll information, is processed by repetitive application of the same or similar computer programs. (This is equivalent roughly to a batch of cookies baked on a single conveyor belt moving slowly through the same oven, subject to identical temperature and time environment.) Interruption of the data processing, once begun, is rare, and the processing workload can be defined accurately.

(4) The output from the computer may be printed reports, tables, graphs, payroll checks, etc. The time frame for decisions arising from the output data usually is not so short as to impinge immediately on the using organization's operations.

In recent years, the emphasis has shifted to "on-line" systems, in which the computer is used directly as an interacting element within the operations of the using organization.

An "on-line" computer system (see Fig. 6-2), as contrasted to an off-line system, is normally defined by these characteristics:

(1) The computer and peripheral equipment are essentially a subsystem of a total information system which extends beyond the physical computer boundaries. Thus, input data are transmitted to the computer directly from the point of origin, and output data from the computer are transmitted directly to the users.

(2) With multiple data sources and users, the terminal equipment at each location, which acts as the man-machine link to the computer, becomes of primary significance. In many systems, the design and operation of the terminal and communications equipment are critical factors, and the computer itself is of secondary importance (assuming a capability above a minimum acceptable level).

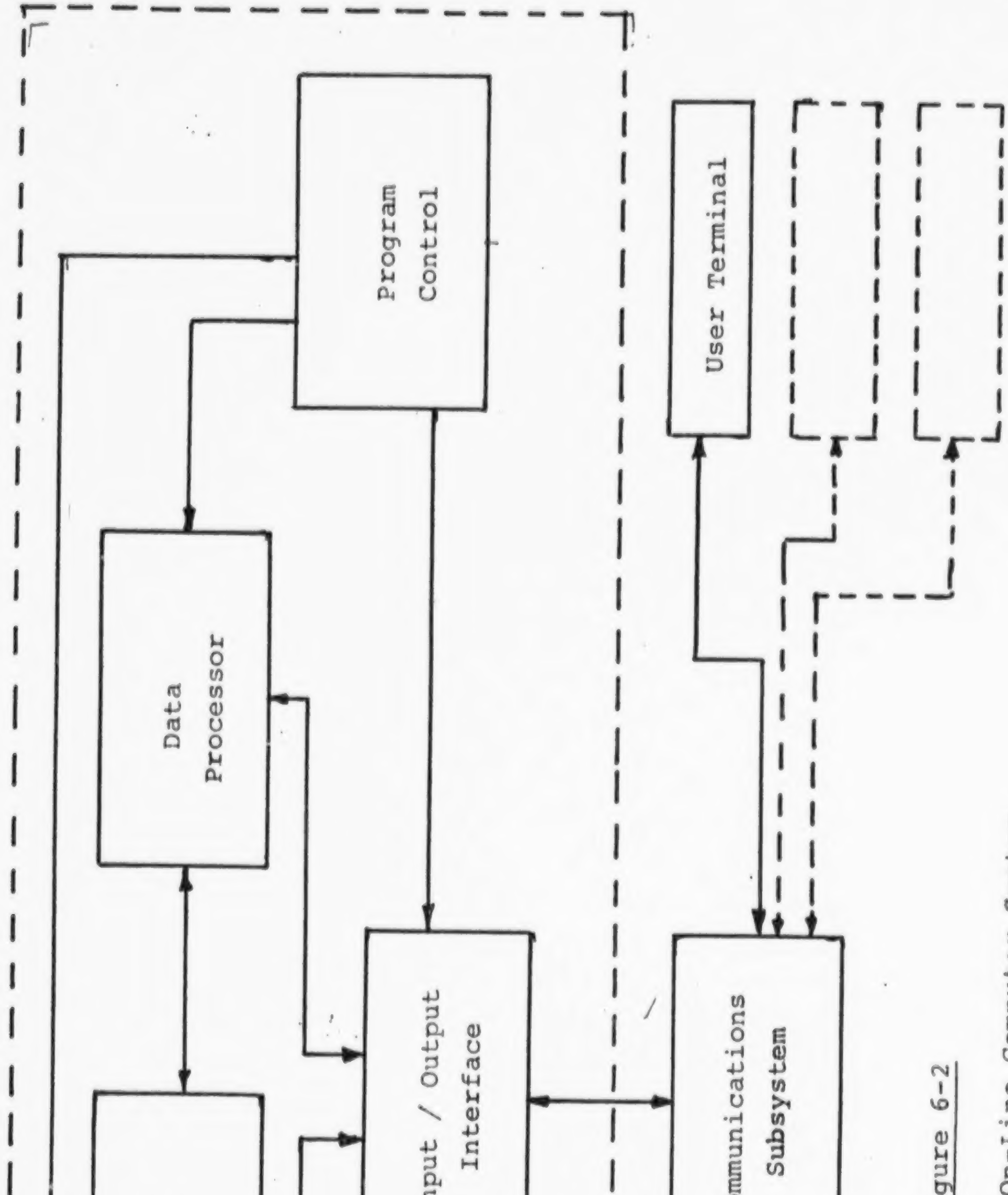

Program Control
Data Processor
Memory
Input / Output Interface
User Terminal
Communications Subsystem

Figure 6-2

Basic Elements, On-Line Computer System

(3) When input data arrive from many sources, possibly in a random time sequence, the computer programming must include provision for establishing data-processing priorities. This can include holding new inputs until previous processing is complete and/or interrupting lower-priority processing upon receipt of higher-priority data. Thus, batch processing, with its orderly progression and rigid control, gives way to processing which must be analyzed through statistical and probability techniques to determine "normal" and worst-case conditions.

Table 6-3 presents a few examples of both off-line and on-line computer applications. The main differences do not involve the computer itself, but how it is used in relation to its input and output. The on-line systems, in effect, bring the computer to a variety of data sources and users, by means of the remote input/output terminals and communications links. At each terminal location, the computer functions directly on a command/response basis with human beings, most of whom have no more familiarity with the technical details of the computer than the average driver has with the engine of his automobile.

So far as educational application of computers are concerned, some of which are described later in this chapter, most operate on-line in the sense that many user terminals, scattered over some geographical area, time-share the same computer. Although the computer is processing many requests in a very short period of time, each user sitting at his terminal is served as if the complete computer facility were solely at his command. Further, the user, whether a student or faculty member, needs to learn only some elementary operational and programming procedures and in a few hours usually can become sufficiently proficient for his purposes.

Apart from an increase in the on-line, multi-terminal mode of computer operation, another major trend has been the use

Industry	Off-Line	On-Line
Airlines	Processing air travel credit card charges, billing	Reservation system servicing passenger requests in real time
Banking	Preparing monthly statements for checking accounts, mortgage loans	Real-time savings account system, updated for each transaction via input/output terminal sets at tellers' windows
Medical	Processing hospital costs, charges, billing records	Continuous monitoring of hospital patient condition, with diagnostic and alarm capability
Retailing	Preparation of monthly payroll, charge account updating, customer billing	Point-of-sale transaction recording, via input terminal, with automatic control of inventory and reprocurement
Education	Processing student test scores and records	Computer-based interactive instruction, concurrently to a number of students

Table 6-3

Typical Computer On-Line and Off-Line Applications of computer systems for noncomputational purposes. A growing number of applications do not rely on the computer's ability to add, subtract, multiply, or divide. Rather, they rely on its ability to receive and store information, to queue messages, to organize data and to control communications.

This trend is as valid for educational applications as for any other. The newer computer-based educational systems, some of which are described in Chapter 12, utilize the computer's computational function only a small percentage of the time, and rely much more heavily on the information storage and management functions noted above. There are many educational systems (e.g., computer-based instruction in a foreign language, or history) which, indeed, do not use any computation capability at all.

Thus, the educator must view the computer less as a very fast calculator and more as an information management tool to be able to estimate accurately its potential for augmenting education.

6-1.3 Range of Computer Capabilities

There are so many types, models and sizes of computers available that even computer specialists cannot hope to know the salient characteristics of each. Further, many of the characteristics quoted by the manufacturer are highly technical, and, in many cases, unstandardized so that comparison is difficult.

Obviously, then, the educator must seek qualified assistance when ready to specify and purchase computer equipment. During the planning and estimating stages, however, a familiarity with a relatively few characteristics can be helpful in "sizing" the proposed system.

Table 6-4 provides an approximation of the range of costs and key characteristics for four arbitrarily defined size classifications of computers, "very large","medium/large", "small/medium" and "mini".

Feature	Mini	Small/Medium	Medium/Large	Very Large
System Cost	$10-30,000	$50-200,000	$300-300,000	$1-5,000,000
Memory Capacity: (a) On-Line Min. Max.	 1,000 words 32,000 words	 1,000 words 64,000 words	 4,000 words 128,000 words	 8,000 words 256,000 words
(b) Off-Line (Fast Access) Min. Max.	 - - 50,000-1,000,000 words	 - - 1,000,000-10,000,000 words	 - - 1,000,000-20,000,000 words	 - - 1,000,000-100,000,000 words
Memory Cycle Time	0.5-2 microseconds	3-10 microseconds	1-5 microseconds	0.5-2 microseconds
Processing Speed: (a) Add Time (full word)	1-5 microseconds	5-50 microseconds	2-20 microseconds	0.5-2 microseconds
(b) Multiply Time (full word)	2-20 microseconds	20-200 microseconds	10-100 microseconds	1.5 microseconds
Word Size (bits/word)	8-16	12-24	16-48	24-48
Number of Instructions	20-80	50-100	75-150	100-300
Communications Data Rate: (a) Min. (b) Max.	 0-50 bits/second 1,000-5,000 bits/second	 (a) 10-50 bits/second (b) 1,000-10,000 bits/seconds	 (a) 40-50 bits/second (b) 5,000-100,000 bits/second	 (a) 40-50 bits/second (b) 50,000-1,000,000 bits/second

Table 6-4

Typical Ranges of Computer Characteristics

The mini-computer will be discussed more specifically in the next section. At this point, it is defined as a computer system whose basic, mimimum-configuration cost is below about $15,000 and whose typical system costs, including options and peripheral equipment is in the $10,000-30,000 range.

The features selected for listing in Table 6-4 are those which convey sufficient information to permit a crude evaluation of the computer system's relative capability. The meaning of each feature is as follows:

(a) Memory Capacity - this is a measure of how much information the system can store. "On-line" refers to the direct-access memory (usually magnetic core) which is part of the basic system. "Off-line" (fast access) refers to auxiliary memory units which can be added and accessed by the system in a relatively short time (milliseconds). It includes magnetic discs and drums but not magnetic tape, since it takes too long to locate data on tape to consider this as fast access.

"Minimum" capacity is the smallest modular memory size available. "Maximum" is the largest size the system can be expanded to, at additional cost.

(b) Memory Cycle Time - this is the time required to "read" a word from memory or "write" one into memory, and is thus a measure of how fast the system can retrieve or store information.

(c) Processing Speed - the times necessary to perform two arithmetic computations, adding and multiplying, are selected to indicate how fast the data processor section of the computer works.

(d) Word Size - the number of bits in a computer "word", which is proportional to the number of characters, (a typical character is 6 bits), provides an indication of how much information can be processed per computing or memory cycle.

(e) Number of Basic Instructions - this gives an indication of how powerful the computer's instruction set is. As a general rule, the more basic types of instructions available, the fewer the numbers of individual instructions necessary to form a program. Thus, programming is easier and less costly.

(f) Communications Data Rate - this indicates how fast information can be received from or accepted by the computer. For an on-line system with many terminals, the "maximum" rate shown is the total for all terminals and can become a bottleneck to the utility of the system.

It is emphasized again that these characteristics, while informative, are by no means sufficient to arrive at a definite decision as to an optimum computer for any particular application. A broad spectrum of other factors, many interdependent with the way the system will be used, must be carefully analyzed. Even with expert guidance, the number of computer-based systems which have not met initial expectations is significant.

From Table 6-4, it can be seen that the cost of a "medium/large" or "very large" computer facility makes its acquisition a major financial project, certainly for educational applications. While large systems are of definite interest, and some are described in Chapter 12, a more recent development has been the growth of mini-computer applications.

Since these hold great attraction for some educational systems, and since their newness makes them more unfamiliar, a brief summary of the features of mini-computers is warranted.

6-1.3.1 Potential of Mini-Computers

Within the last few years, the cost of microelectronic circuitry has dropped sharply. Standardization of circuits and high-volume production, plus the achievement of better yields in high-density packaging (such as building hundreds of circuits on a tiny wafer as in Large-Scale Integration) have combined to make possible for the first time low cost yet surprisingly powerful computers.

This category of mini-computers is separated from other computers in cost and size alone. Otherwise a mini-computer has all the features of a larger unit.

The dividing point is somewhat debatable, but it is usually accepted that any computer system, including peripherals, that costs less than $25-50,000 (the exact price depends upon whoever is doing the defining) is a mini-computer.

The basic components of the mini-computer, the processor/control unit and the smallest module of memory, currently cost from about $2,500 at the low end to about $15,000 at the high. To this minimum configuration must be added peripheral equipment and, depending upon requirements, more memory modules as the system expands, resulting in the $25,000-50,000 total system cost noted above.

Obviously, the most attractive feature is the reduced cost. There are now educational time-sharing systems, using mini-computers, which can handle 8 terminals for a total system cost below $40,000 and up to 32 terminals for about $80,000. This makes the use of small, on-campus systems much more attractive.

It is interesting to note, from Table 6-4, that many of the features of mini-computers, such as processing speed, are as good as the large and very large systems. This is due to the use of the same types of electronic circuitry, although in smaller quantity.

There are some disadvantages to mini-computers, at least in their current state of development. First, the use of smaller word lengths presents some difficulty in data manipulation. Secondly, the restricted amount of memory space available places a premium on programming so that efficient use is made of the room that is available. Since the most efficient type of programming is in machine language, as previously noted, many users are forced in this direction if their application requires all the memory available. Thus, the advantages of more convenient programming languages such as BASIC may be lost, or conversely, if used will require the addition of more memory to the system.

A third problem is that, unlike the main-frame and memory, the cost and size of peripheral and input/output equipment have not gone down proportionately. A teleprinter, for example, is the same in either a large system or a mini-computer system, and costs the same in each case. Some progress has been made in a few areas. Magnetic tape cassette units are becoming available with a reduction in cost, and smaller disc storage units are being designed especially for mini-computer applications. As a general rule, however, many items of peripheral equipment are over-designed, over-sized and over-priced for mini-computer systems, and consequently they dominate the systems' overall cost-effectiveness.

This condition will be remedied, however, and the growth in mini-computer systems seems assured. The key factor is that when the cost gets low enough, many applications which formerly could be handled only through a large centralized facility can now be localized and decentralized (see 6-2.4.1).

6-1.4 Software Considerations

As anyone with computer experience is well aware, the importance of the software cannot be over-emphasized. Properly conceived and implemented, computer programs can direct the system to operate with amazing efficiency, while conversely, poorly developed programs can render an expensive installation almost worthless.

Despite its criticality, software (which as used herein means everything necessary to make the computer system work except the physical equipment) has been and remains more of a craft than a science to even its professional practitioners. To the educator who wishes to use a computer system, it can be the area of least familiarity and highest difficulty.

The manufacturer of each computer generally supplies a software "package" which includes the general-purpose operating system and executive programs, and perhaps some self-test or diagnostic programs. Documentation is also available in the form of manuals which explain what these programs are designed to do.

At this point the computer system can be used for a variety of general-purpose tasks. Indeed, libraries of programs are available, either from the manufacturer or from user organizations, which can increase the number and scope of these tasks.

For almost any new application, however, a group of special-purpose programs must be developed. For an instructional system, as an illustrative case, the content of the curriculum has to be translated into computer operations, and the capability for query and response, with a variety of possible combinations, also has to be programmed.

These application programs (which for many systems can represent more man-years of programming effort than the general-purpose software) can be produced in many ways. The educator, for example, can provide the computer manufacturer with his objectives and course material and the manufacturer can develop the applications program package.

This removes the programming burden, and in many cases is reasonably satisfactory, but suffers from some disadvantages. Costs are high, since the manufacturer is diluting his primary effort into a specialized area, and indeed some manufacturers are not interested at all in doing this.

The major problem, however, is that the achievement of the users' objectives, in this case educational, is delegated to someone who has admitted computer expertise but possibly not enough knowledge of the educational process. Distortions of intent will occur inevitably, and may be major. The educator-user cannot be sure that the distortions are due to the inherent limitations of the computer, or to the delegation process.

Obviously, close coordination between the user and the software developer, whether it be the computer manufacturer or independent software specialists, will help to minimize this problem. It still remains as a serious one, however.

One way of improving the situation is for the user to gain some familiarity with programming techniques. This does not imply becoming expert, but learning enough to provide a better degree of coordination between the objectives and the resulting programs.

As a case in point, when NASA experienced its great period of initial growth, in the early and middle 1960's, the problem arose of testing the new rocket boosters and space vehicles by means of computer-based testing systems. The question arose as to how to transfer the very specialized skills of the aerospace test engineers into the required programs. The alternatives were:

(1) train the cognizant aerospace test engineers in programming and have them develop the programs
(2) train experienced programmers in aerospace testing
(3) use teams of engineers and programmers working together

In practice, all three alternatives and hybrids of them were utilized, with the third being perhaps the most prevalent because of the urgent time constraints. Where time and manpower permitted, however, the first alternative proved to be much more efficient. It was easier for an aerospace engineer to learn programming than for a programmer, who usually had less scientific and engineering training, to learn enough about the test requirements to be efficient in translating them for the computer.

The same probably holds true for educational computer systems, (or medical, legal or any other highly professional application), and where a teacher or faculty administrator can and does become familiar with programming, the best results can be achieved.

Quite apart from the technical aspects of programming, it must be realized that the software represents the "master plan" for the system, and must be conceived and structured to do what the user wants done. This is not necessarily the same as making the programming task easy for the programmers.

Figure 6-3 illustrates, in simplified form, the planning and development cycle for a computer system and is as valid for education as any other application. The cycle begins with the initial user motivation which may or may not result in a decision to develop the system. In most cases, a justification analysis is necessary to determine whether the contemplated system appears feasible and can meet preliminary objectives.

Once the decision for implementation has been reached (the "Yes" of Figure 6-3), the user must define:

(a) What the System Should Do - Since an on-line computing system is basically an information distributor with the information used for a variety of purposes (control, decision-making, reporting, etc.), defining what the system should do may be considered the equivalent of establishing the information flow and format requirements.

Ideally, the user should define these objectives before the constraints of available hardware or standardized software are applied, rather than permit the latter to inhibit the desired information flow. The idealized objectives necessarily will be modified if they cannot be achieved realistically, but their initial establishment at a user level sufficiently high to be able to weigh all relevant factors is the crucial point.

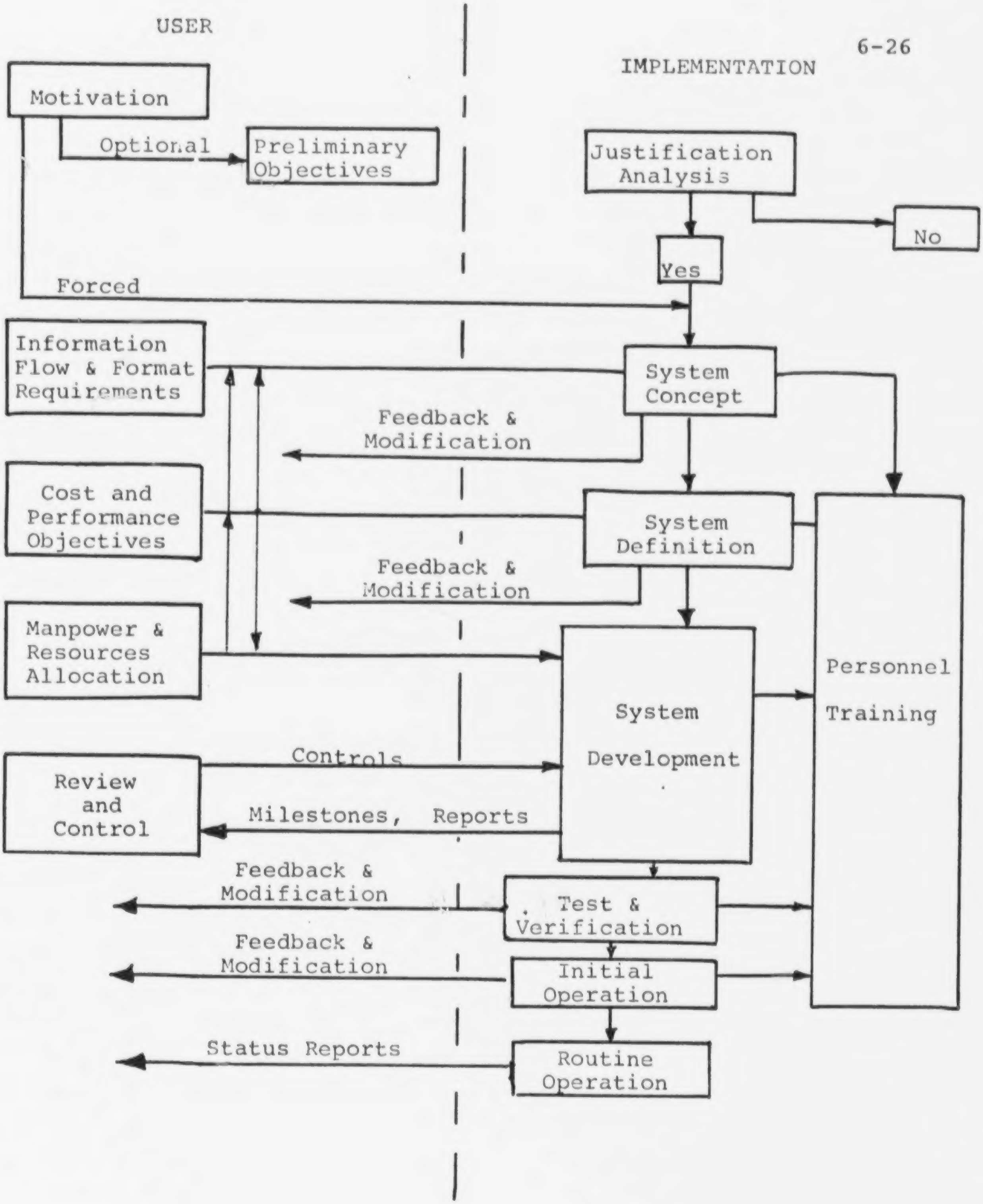

USER
IMPLEMENTATION
Motivation
Optional
Preliminary Objectives
Justification Analysis
No
Yes
Forced
Information Flow & Format Requirements
System Concept
Feedback & Modification
Cost and Performance Objectives
System Definition
Feedback & Modification
Manpower & Resources Allocation
System Development
Personnel Training
Review and Control
Controls
Milestones, Reports
Feedback & Modification
Test & Verification
Feedback & Modification
Initial Operation
Status Reports
Routine Operation

Figure 6-3

System Planning and Development

The defining of this flow dictates the final software structure. The more detailed the definition, the fewer the difficulties which usually arise when the software is considered in depth only after the computer hardware has been sized and selected.

Decisions on the desired information flow and format are no different from the normal management responsibility to establish the ground rules and over-all requirements for any complex project. The dominant feature of on-line computing systems, as compared to other equipment systems, is the dependence upon software which in most cases requires a major special-purpose, one-time development effort. This area simply is too vital to be permitted to proceed without adequate management definition and control.

(b) How Much the Desired Performance is Worth - The information flow and format requirements, in most cases, will not be fixed within rigid limits, but rather will permit a range of performance ranging from "ideal" down to "barely adequate". This spectrum must be correlated with a corresponding range of estimated costs for the contemplated system. Again, this concept is not unique to computer systems, but the emphasis on "total cost" is especially critical. The environment for on-line systems is exceptionally fluid and subject to change, and historically, this has led to gross underestimates of both the initial and sustaining costs of software.

An expression often used to describe real-time systems is, "Pay for the hardware once; pay for the software forever". The point made is that users should expect and be prepared for a substantial continuing effort in upgrading and modifying software, unless the operating environment is unusually static. Allowance for this continuing effort will increase the estimated total cost, which in turn will provide a more realistic appraisal of the system's cost-effectiveness.

(c) How the System will be Implemented - Together with cost and performance objectives, the method of implementing the proposed computer system is also the concern of management. How the system will relate to the total organization, the assignment of manpower and resources, departmental responsibilities and controls, and interdisciplinary training must be considered as dynamic elements of the computer system and, to the extent possible, defined and structured.

Implementing the system may dictate a realignment of traditional departmental and individual responsibilities. The related procedures and personnel relationships may well require considerable time before realization.

After the preliminary objectives and contraints have been defined, a system concept can be formulated. At this point the help of computer experts can be enlisted, and a range of available computer hardware and software configurations evaluated to arrive at relative figures of merit.

From the conceptual phase through the initial system operation, there is a continuous feedback and modification process, in which the status of the system is compared against initial and updated objectives and appropriate changes made.

With the acceptance of a conceptual design, the implementation proceeds into the system definition phase. Here, firm hardware and software specifications are prepared and interface requirements defined and controlled. These, when approved, form the basis for selection of the most suitable computer, peripheral and terminal equipment, and for structuring the software.

The entire effort to this point is part of the initial analysis of objectives, and the translation of these objectives into documentation sufficiently precise to permit implementing the system with a high expectation of adequacy and efficiency. Up to this point, theoretically, no commitment is made to specific hardware procurement or computer programming.

Understandably, this process is expensive and time-consuming. The bulk of experience to date indicates, however, that extended effort in this initial stage almost invariably reduces the total system cost and development time, and increases its efficiency by orders of magnitude. If any generalization can be made with certainty, it is to recommend erring in the direction of more effort, rather than less, in the planning and definition stages. Revisions can be made without the multiplied cost and time penalties implicit at later stages, when hardware is in being and thousands of manhours of programming have been completed.

6-2 Educational Applications

The use of computer-based educational systems is still in its infancy, although many pioneering efforts have been in operation long enough to arrive at some preliminary evaluations, at least. Because of the computer's power and flexibility, it is certain to be used more in the future, and in ways which have not yet been conceived.

"Machine teaching", in which automated devices were used to assist instruction, was initiated in the 1920's, even before the development of the computer. Many devices were developed during the course of the years, and continue to be developed at present. Most were conceived by non-educators, priced relatively high, and did not demonstrate any significant instructional advantages. The focus invariably was on the hardware, with most products being incompatible with any others. The software, in many cases, provided no greater instructional value than did programmed textbooks. As a result, the use of teaching machines never attained widespread acceptance.

In the late 1950's and 1960's, a growing number of digital computers on college campuses, which were acquired for scientific research or for accounting and record-keeping, became available for other applications. Faculty members, some of whom had computer experience, became interested in developing educational systems and, in some cases, obtained sufficient financial sponsorship to develop sizeable projects. In parallel with this, a few computer manufacturers began to take interest in the market for educational systems and offered specialized products and software for sale.

Some typical systems are described in Chapter 12. Before these can be evaluated, however, a brief discussion of the ways in which computers have been applied to education may be helpful.

6-2.1 Computer Assisted Instruction

Computer Assisted Instruction (CAI) is the utilization of a computer to guide a student through a programmed course of instruction, with the computer as an active element of the instructional process. Other names for essentially the same technique are Computer-Aided Instruction, Computer-Augmented Instruction, Computer-Administered Instruction, all designated CAI. Occasionally the word "Learning" is substituted for "Instruction", resulting in "CAL".

In the narrow sense, CAI implies a computer program developed for a specific course which presents to the student a planned sequence of instructional material, through a remote terminal. Used more broadly, it can include all uses of the computer for education, including data processing and problem-solving computation.

In simplified form, the following guidelines are characteristic of CAI:

- (a) Both the instructional content and testing material are stored in the computer memory
- (b) The instructional content is structured in terms of measurable student performance objectives
- (c) The rate of instruction is controlled by each indivdual student. Each student may be at a different point in the "course" at any given time.
- (d) Information feedback (e.g., test results) is used to attain individually responsive instruction.
- (e) Knowledge of results and progress is provided to students on an immediate basis. Progress to a new increment of instruction usually requires correct response to prior increments.
- (f) Recycling through any portion of the program is permitted.
- (g) Instructor assistance is available for students encountering difficulty
- (h) Instruction is modularized, with each module containing:
  - (1) a "pre-test element" - which enables a student to pre-test himself and skip material he already knows
  - (2) a "lesson element" - the instructional material
  - (3) a "review element" - a review and/or test for mastery of the objectives established for the lesson module.

Figure 6-4 illustrates the information flow of a typical CAI system. The student begins at the pre-test element and answers questions directed at him by the computer. If he passes the pre-test, he can skip the lesson and review elements and proceed directly to the next lesson module.

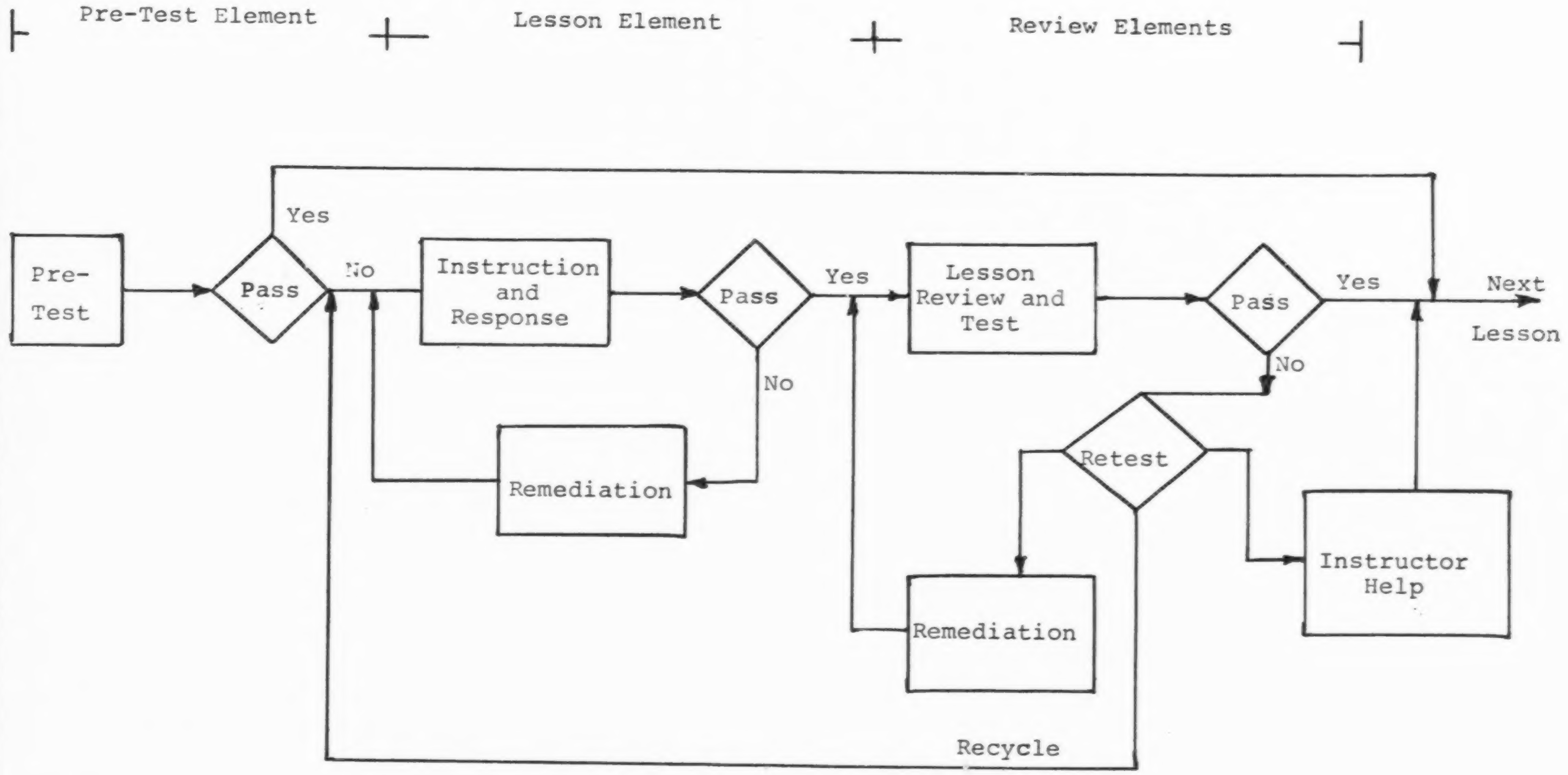

Pre-Test Element
Lesson Element
Review Elements
Pre-Test
Pass
Yes
No
Instruction and Response
Pass
No
Yes
Remediation
Lesson Review and Test
Pass
Yes
No
Retest
Remediation
Instructor Help
Recycle
Next Lesson

Figure 6-4

Information Flow - CAI System

If he does not pass, he is required to continue into the lesson element. Here, depending on how the course is programmed, he receives a combination of problems and instruction which are designed to teach him the subject. These are presented in a sequence so that the student must understand a particular step before proceeding to the next.

At the end of the lesson element, the student is tested again. A "pass" permits him to proceed to the review element, while a "fail" requires that he take a remedial instructional sequence and go through the lesson element once again.

The same procedure holds for the review element, except that the computer judges the final test results and, if the student fails, classifies the degree of failure to determine appropriate action. The student may be directed to undergo another remedial sequence, or recycle back to the beginning of the element, or seek assistance from the instructor.

Obviously, CAI is more easily adapted to courses which are fact and logic-oriented (e.g., mathematics) and least adaptable to subjects in which "right" and "wrong" answers are difficult to define (e.g., philosophy, creative writing). Further, even in a course such as mathematics, only a portion of the course material may lend itself easily to CAI technique.

It is also clear that the value of any CAI course depends greatly on the software, i.e., that is, how good a job has been done in translating instructional procedures to computer form. This task requires close interdisciplinary cooperation between educational and computer specialists.

To date, a number of CAI operational modes have been developed, on an ascending scale of sophistication. The most common are described below.

6-2.1.1 Drill-and-Practice

The "drill-and-practice" mode is the simplest CAI application The computer stores practice exercises in increasing degrees of difficulty, and presents them to the student in that sequence. By using the memory capacity of the computer and its ability to monitor a number of students concurrently, the teacher is relieved of the burden of repetitive drill and supervision. Thus, drill-and-practice is designed to supplement the teacher's duties, or, at best, to assume the more routine functions, rather than to present new instructional concepts.

In this task, the computer undoubtedly is very efficient (and patient), and readily permits each student to proceed on an individualized basis, both as to level of difficulty and rate of presentation.

6-2.1.2 Tutorial

The "tutorial" mode of CAI is more advanced than drill-and-practice, endeavoring to present to the student essentially the same information as might be contained in a programmed textbook. The computer program assumes responsibility for specific instruction, and approximates the tutor-student relationship.

The justification for using a computer lies in its ability to store many contingent instruction modules, selecting the appropriate path to match the student's progress. With this "branching" capability, the student can more easily evolve or construct the answer rather than simply select one from two or three choices.

Because it attempts a more complex instructional mode, tutorial CAI naturally is more difficult to program than drill-and-practice. A broader range of student responses must be anticipated, and provided for (including even such minor technicalities of recognizing mispelled words). If the advantages of the computer are not utilized efficiently, the cost of this CAI mode can be intolerably high.

6-2.1.3 Inquiry/Response

In the "inquiry/response" mode, an interactive or conversational dialog takes place between the student and the computer which goes beyond simply matching student answers with a list of acceptable responses stored in the computer's memory.

In a simple dialog system, the student is free to make a wide variety of responses which are judged by the computer. In a language program, for example, the student could begin to write complete sentences after having received very little prior instruction. The computer would tell him what he is doing correctly in each case, allowing the student to "zero in" or converge upon an acceptable form after a number of attempts. Thus, learning is achieved by discovery, or trial and error, than by a structured "right/wrong" instructional program.

More complex dialog systems would allow even wider latitude in student inquiry, with the objective of achieving a Socratic model of instruction. As this objective is approached, however, great difficulties arise in programming the computer. Ideally, the student should be able to enter his questions in "natural" language, which would be properly intepreted by the computer. As yet, the programming "languages" which have been developed are highly restrictive, forcing student inquiries to conform to the limited rules of the program language utilized.

Some progress has been made in selected systems, but to date the dialog systems which have been implemented are relatively narrow in scope. The full potential of this technique awaits the refinement of "higher-level" programming, i.e., approaching natural language so far as the user is concerned.

6-2.1.4 Problem-Solving and Computation

The "problem-solving" CAI mode consists of using the computer as a computational tool rather than a textbook, with less reliance on a body of data stored in the computer memory.

In a simple application, the computer acts as a high-speed calculator to do the computation required to solve a problem that might otherwise be too difficult or lengthy. A problem such as computing the value of "π" to a high degree of precision (at last record a computer has actually done this to over 2000 places) would simply be unmanageable without the computer.

A more complex application permits the computer not only to compute, but assist in the problem-solving process by evaluating each step and indicating errors as they occur. This can be done by giving the student access to a number of pre-programmed routines which can not only perform calculations, but can be combined for error checking.

Computation need not be a separate mode in itself, but can be combined with other CAI modes such as inquiry/response. The programming becomes more difficult in this case, and to some extent, computer efficiency is reduced since a compromise must be effected between the predominately memory-oriented instructional process on the one hand and the computation-oriented problem-solving routines on the other.

6-2.1.5 Modeling and Simulation

A promising application of computers to instruction is that of "modeling" and simulation. These techniques have been used extensively in "war games", system design, business forecasting, etc., but are relatively new in education.

A typical example in a business administration course, for example, would be to set up the characteristics of a company in the computer, including past history of sales, earnings, operating ratios, competitive factors, product development, etc. Then a set of assumed conditions for the future could be given to the students such as national economic conditions, potential new markets, technology trends and any others deemed relevant.

The student is then requested to decide upon specific action to be taken, constituting in effect a business plan. These actions are entered into the computer, which is programmed to evaluate their effect upon the company. This effect, in the form of projections of future sales and profits, is then presented to the student.

The advantages of a computer in such a simulation exercise are that it can quickly analyze the combined effect of many parameters (but only in accordance with the rules of the game, its programmed instructions). Thus, a 20-year projection can be calculated in minutes or hours.

Further, the rules can be changed if desired, permitting evaluation of many combinations and ranges of influencing factors, again in a short time. This task, like the difficult computational job discussed above, simply could not be done any other way without excessive cost or time being expended.

As might be expected, the value of such simulation depends completely on how accurate the model is, and whether the program rules are flexible enough to embrace the numerous possibilities worthy of exploration. If a process is not understood well enough to construct an acceptable model, the power of the computer to mislead can be as strong as its power to illuminate.

6-2.2 Computer-Managed Instruction (CMI)

Computer-Managed Instruction (CMI) involves the use of computers primarily as tools for evaluating student progress and matching students with instruction appropriate to their individual needs rather than actually performing the instruction.

Thus CMI depends upon the resources of conventional textbooks and audio/visual devices, in addition to the human instructor, and acts more in diagnostic and administrative support of the instructor.

Some of the functions implicit in CMI include:

(a) testing students and evaluating test results, usually at a number of stages in the course.

(b) Matching test results with appropriate learning prescriptions.

(c) limited use of drill-and-practice CAI, again primarily as an evaluation device and for remedial purposes.

(d) development, maintenance and supervision of student instructional histories.

The data base developed by CMI systems which have been operating for some period of time can be used as a guide to improve CAI techniques and programs. With iterative refinement, not only can CAI be optimized for the majority of students, but special versions can be produced for the minority of "exceptional" students, either in the advanced or retarded category.

Many variations of CMI are possible, from a simple record-keeping system to one with interactive diagnostic and counseling capability, in which students are guided to the appropriate instructional materials by the computer, which in turn has been supplied with student progress records by the instructors.

6-2.3 Information Storage and Retrieval

In _information storage and retrieval systems_, the computer's prime function is to _store_, _provide access to_, and _distribute information from a "data-bank"_. The flow of information, particularly from the computer to the user, may be relatively large compared to an interactive system.

The information stored and retrieved may be in direct computer-compatible form, such as coded alphanumeric data in the computer's memory. It may also be in non-compatible form, such as microfilm or video tape, in which case the computer controls the _means_ for _selecting_ the appropriate information, but the transmission back to the user is non-digital and essentially outside the computer's purview.

In this category are included information networking, dial-access audio/visual, and computer-based mixed-media systems.

There is considerable overlap between the retrieval and interactive systems. For example, a computer system may include the dual capability for interactive problem-solving and also accessing a large data-bank. Nevertheless, the separation is useful from a technological point of view, as the information storage, communications and display characteristics differ markedly.

In a problem-solving system, there generally is a low volume of data tramsmitted between the computer and any user terminal. This is partly because of the nature of the terminal itself, usually a slow-speed teleprinter, and partly because of the inherent delays in CAI, primarily at the user end while the student is deciding how to respond.

Thus, in many cases, a very low bandwidth communications link is adequate. Voice-grade telephone lines are entirely satisfactory for single-user connection and, in fact, are used as "party lines" in most systems, to accommodate a number of user terminals.

For a retrieval system, the low bandwidth link may be adequate for user-to-computer communications, in which a request is transmitted. For the response, this is not true. If, for example, the request is for receipt of a TV program, a wideband communications link is necessary.

Even for retrieval of static visual data, such as still pictures, pages of a book, etc., telephone links impose an operational handicap. As noted, the transmission of one 8-1/2" x 11" page by facsimile normally requires some 3-6 minutes over telephone lines. While this may be adequate for isolated cases, it would hardly be compatible with a general purpose, multi-user retrieval system.

The features of the user terminal also vary greatly between the interactive and retrieval computer system. The interactive system can use a teleprinter terminal because the time interval of the user inquiries and the computer's response are reasonably compatible with the speed and printout capability of the terminal.

For a retrieval system, the user's terminal may not differ in the "request" capability. The "response" portion of the user's terminal, however, must match the characteristics of the data being retrieved and may correspondingly be much more elaborate and expensive. If a TV video/tape is being accessed and retrieved, the user's terminal must in effect be a TV receiver. If visual/static graphical or microform data is retrieved, then perhaps a facsimile hard copy receiver is required. If library interchange of large quantities of alphanumeric data is the objective, a high-speed line printer may be the receiving terminal device.

For interactive problem-solving, the computer memory storage is not required to store and provide access to very large quantities of essentially similar data. On the other hand, the software library, i.e., the programs necessary to solve the wide variety of problems anticipated will be extensive. Thus, the interactive system is useful in proportion to the comprehensiveness and variety of its library of "applications" programs. Any specific program may be used relatively rarely, however, and in almost all cases the quantity of data manipulated and transmitted in either direction is relatively small.

Conversely, the networking/retrieval computer system stores a vast amount of data, ordered and filed so as to be accessible within acceptable time limits. Essentially no computation or data processing is done, but the software in this case acts as a traffic director. The critical functions of the software are large-file management, data access and control of communications. The computer, in this instance, "computes" very little but serves as a data repository, i.e., a library with its attendant functions.

From the above summary of characteristics, certain operational conclusions may be inferred. The interactive system permits the computer and user to interface at an input/output rate more convenient to the user. In other words, the man-machine interface is designed more for the slower human rates than for the computer. For this reason, use of the computer in the interactive mode usually is not cost-effective unless a large number of users can be served.

The information networking or retrieval system, on the other hand, is usually not cost-effective unless a great deal of data can be communicated to the user in a short time, in most cases shorter than the time required for utilization of the data. Thus, a retrieval system (except for the extreme cases where only small quantities of data are retrieved) is more efficient as a machine-to machine system and is constrained, sometimes drastically, by the man-machine output interface, i.e. the user terminal.

6-2.4 Selection of Computer Systems

It is clear from the foregoing discussions that selection of a particular computer as the optimum for an educational application is not an easy task. In most cases, this decision has been either abdicated or rendered moot because a specific computer was already available and had to be used, or because a standard system was purchased from a manufacturer. Examples of the latter are the IBM 1500 Instructional System or RCA's Educational 70 System.

There are no rules which can guide the educator automatically to selecting the best hardware/software configuration from a maze of possibilities and in most cases expert advice and consultation is necessary. The critical factor, however, is that the educational user must first define the requirements of the system and then modify these, if necessary, to fit equipment constraints, rather than than accepting a recommendation for a specific system and then trying to fit his educational needs to that. The first case permits him to know exactly how much he is deviating from his objectives, the second does not. This is even more true in the software area than in hardware, since the questions of what is presented to the student, and how it is presented, determine whether the system gains acceptance and represents any improvement over present methods.

6-2.4.1 Centralized vs. Decentralized Computers

One basic decision which must be reached in any widespread educational use of computers is the choice of whether a centralized or decentralized system approach should be used.

A centralized system is one which uses a single, large-scale computer to serve many user terminals and locations. The computer might be a facility costing millions of dollars, and could serve a region of schools and universities, possibly with thousands of terminals. Since a large geographical area is served, the terminals are linked to the computer by communications networks, usually telephone lines.

A decentralized system would use small computers located at each using facility, e.g., one per school. The small computer could serve a much smaller number of users, but enough for that location. The connection from computer to user terminals is usually direct-cable, paid for and owned by the using institution.

There are advantages and disadvantages to each approach.

(1) Centralized:
  (a) The large computer offers "economy of scale" performance, i.e., it gives more computing power per dollar.
  (b) Program preparation can also be centralized and and made more efficient. Further, programming effort does not have to be duplicated at each location, and a large library can be built up for everyone's use.

- (c) The computer can be operated and maintained by a group of skilled professionals who would not be obtainable by smaller facilities

(2) Decentralized:

- (a) The system is not dependent on costly, and sometimes unreliable communications links.
- (b) The system can be "dedicated" to a single application and optimized for that, instead of having to be able to serve in a variety of applications.
- (c) Changes, in both hardware and software, can be made much more quickly and easily.

At this point in time, no clear-cut choice can be made for all cases, but it is likely that decentralized systems will proliferate faster than centralized ones. This is partly due to the jurisdictional and budgetary quirks of U.S. school districts, where smaller sums are more easily come by, and partly to the expectation that mini-computer systems will become even more attractive in cost and performance.

The software requirements of the decentralized systems, however, will represent a substantial challenge to local educators and, if this challenge is not met, the utility of such systems could prove disappointing.

6-2.5 Costs of Computer - Based Instruction

It is extremely difficult to determine the precise costs of a computer-based educational system. Historical records of prototype systems are available, and provide the best sources of data, but even there a number of interrelated factors tend to blur the evaluation. Some of these are:

(1) The computer in many cases is being used not only for instruction but for other tasks such as record-keeping and accounting.

(2) The cost of preparing and updating programs may fluctuate wildly, dependent upon whether they are prepared by local faculty or not, and whether the curriculum requires drastic revision to be compatible with the computer. Another factor is the possible availability of programs already prepared by other educational institutions, in which case this cost may drop almost to zero.

(3) The cost of operating and maintaining the equipment, which may range from students doing these tasks on an uncompensated basis as part of their training to a full-time professional staff.

(4) The number of instructors required to monitor the computer and students, supervise the instruction and coordinate results.

(5) The long-term upgrading of program material, both to improve instruction in the light of past results and also to keep the curriculum material up to date. This cost is determinable only after some years of system operation.

As a result of these variables, cost estimates for computer-based education have been quoted at anywhere from $0.20 to $10.00 per student-terminal-hour, a 50:1 range.

Tables 6-5, 6-6 and 6-7 provide typical, rather than definitive costs, and should be so viewed.

Table 6-5 shows cost vs. coverage for the large, centralized computer approach. The New York City pilot CAI system and the Dartmouth-Time-Sharing-System have been used as examples. It is interesting to note that although one utilizes CAI and the other conversational interaction, the costs per terminal per hour are, for all practical purposes, the same at present.

Table 6-6 provides similar data for two currently available, small, dedicated educational computer systems. It can be noted that the cost per terminal per hour is reduced about 50-60%. This is counterbalanced, however, by the fact that the smaller computers are more limited in both capability and flexibility, and require more sophisticated programming in many cases.

Table 6-7 compares the cost of a CAI course in college physics at Florida State University against a CMI project also developed by the same staff. As expected, the CMI costs are much lower.

Cost Item	Case A - New York City CAI System/Spectra 70/192 Terminals 1968-69 Actual $ Costs	Cost Item (per Sec. School/Yr.)	Case B - Dartmouth Time-Sharing System, Average Costs
Computer (Hdw. Only)	190,000	Computer (Hdw. Only)	4,350/Schl./Yr.
Communications	130,000	Communications	2,720/Schl./Yr.
Software & Personnel	195,000	Software & Personnel	-
Total Annual Cost	515,000	Total Annual Cost	7,070/Schl./Yr.
Cost/Terminal/Year	2,680	Cost/Terminal/Year	2,470
Cost/Terminal/Hour (Assuming 1500 Hrs./Yr.)	1.70	Cost/Terminal/Hour (actual use 1860 hr./yr./Term)	1.77
Mode	CAI	Mode	Interactive - Conversational

TABLE 6-5

Cost vs. Coverage - Educational Use of Time-Shared Computer

Large, Centralized Computer System - Urban Area

Cost Item	Case A - Computer Curriculum Corp. 8-Terminal System	Case B - Educational Data Systems Alpha 300 (8-Terminal System)
Initial System Cost	30,000	24,900
Imputed Annual System Cost (10% interest, 8 yr. life)	4,640	3,850
Est. Annual Maintenance (10% Cost)	3,000	2,490
Personnel & Training Annual Cost	2,500	2,500
Total Annual Cost	10,140	8,840
Cost/Terminal/Yr.	1,267	1,105
Cost/Terminal/Yr. (Assuming 1500 hrs./yr.)	0.84	0.74

TABLE 6-6

Cost vs. Coverage - Educational Use of Time-Shared Computer
Small, Dedicated; In-House Computer System

CATEGORY	CAI ITEM COST	CMI ITEM COST
Curriculum Preparation	(K = Thousand Dollars)	
Behavioral Scientists	12K	0
Writers	12K	1.3K
Physicists	6K	
	30K	1.3K
CAI Coding		
CAI Coding Personnel	12K	4.3K
Computer Time	10K	3.5K
	22K	7.8K
Film and Graphics Production		
Art Work and Service Cost	6K	.2K
	6K	.2K
Computer Programming		
Data Management Programming	54K	0
Data Analyses Programming	15K	0
	69K	0
CAI Instructional Cost		
CAI Computer Costs	15K	.9K
Proctors	3K	0
	18K	.9K
Experimentation		
Graduate Students	24K	.8K
	24K	.8K
Office and Clerical	10K	0
University Overhead	60K	0
TOTALS	239K	11K
Cost per Instructional Hour		
a. Development	$4.07	$1.04
b. Operations	1.79	.59

TABLE 6-7

Cost for a Collegiate CAI Physics Course and CMI Course Curriculum Development Project at Florida State University

CHAPTER 6 - BIBLIOGRAPHY

1. "Computers in Higher Education", Report of the President's Science Advisory Committee, 1967, Government Printing Office, Wash. D.C.

2. "Educational Technology in Higher Education: The Promises and Limitations of ITV and CAI", Report, Instructional Technology Committee, Commission on Education, National Academy of Engineering, Sept. 1969.

3. Hansen, D.N., "The Role of Computers in Education During the 1970's", Tech. Memo No. 15, May 15, 1970, Florida State University, prepared under Contract No. N00014-68-A-0494, Office of Naval Research.

4. Levien, R.E. (Editor), "Computers in Instruction: Their Future for Higher Education", Proceedings of Conference Oct. 1970, sponsored by NSF, the Carnegie Commission on Higher Education, and the Rand Corp., Rand R-718-NSF/CCOM/RC, July 1971.

III. CARRIER AND DISTRIBUTION SUB-SYSTEMS

Chapter 7 Distribution Techniques
Chapter 8 Wire Carriers
Chapter 9 Wireless Carriers

CHAPTER 7 - DISTRIBUTION TECHNIQUES

Information in electrical form may be distributed in a variety of ways. Some of the questions which must be answered before a choice of distribution systems can be made include:

(a) What is the form of the electrical signal as it enters the distribution system?

(b) What is the desired information flow (i.e., how many sources, how many receptors, one-way or two-way communications)?

(c) Can the original electrical form be transmitted efficiently?

(d) Are there many signals to be distributed over the same paths?

(e) What form is desired at each reception point (to match the receiving terminal)?

(f) What are the relative costs of alternate distribution methods?

(g) What constraints are there (e.g., FCC allocations of frequencies)?

Even after the answers have been determined, the selection of an optimum system is not always clear, and in many cases may require the services of communications specialists.

This chapter reviews the basic concepts involved in transmitting and distributing electrical information. Chapters 8 and 9 focus, respectively, upon wire and wireless carriers.

7-1. Communication Modes

7-1.1. Transmission Medium

Electrical signals can be transmitted as a current through electrically conductive material, such as wire and cable, or they can be sent through space as an electromagnetic radiation. Both media are in wide use, and almost all systems combine the two for different portions of the transmission path. A radio broadcast station, for example, will use wire to feed the signal to the transmitting antenna, and wireless from that point to the receivers.

Fig. 7-1(a) is the generalized diagram of any electrical distribution system. There must be a source of electrical power which forces the flow of electrons in a wire, or radiated energy through the air. This power must be used by a load of some sort, and, finally, there must be a complete path for the electrical flow.

Fig. 7-1(b) is an elementary sample of wire transmission. The battery forces electrical current through the resistor, which uses (dissipates) power, and around the complete circuit.

Although metals are more highly conductive to electricity (offer less resistance) and are therefore commonly used for wires and cables, they are not the only materials which can transmit electricity. All materials, in fact, will conduct some amount. Those which, for practical purposes, conduct an insignificant amount are called insulators, while there is a category which permits some conduction but not so much as the metallic elements.

The earth itself will conduct electricity with varying degrees of resistance, depending upon ground conditions between the points of entry and exit. Thus, in Fig. 7-1(c), the earth between the two "ground"connections will complete the electrical path, allowing some current to flow.

Since the metallic wire or cable is a much better conductor than the earth, and also subject to less interference from outside signals, most wired systems provide complete paths without depending upon a ground return path for the normal flow of current. Many systems, however, use a metal case or chassis as a common connection point, which is also called

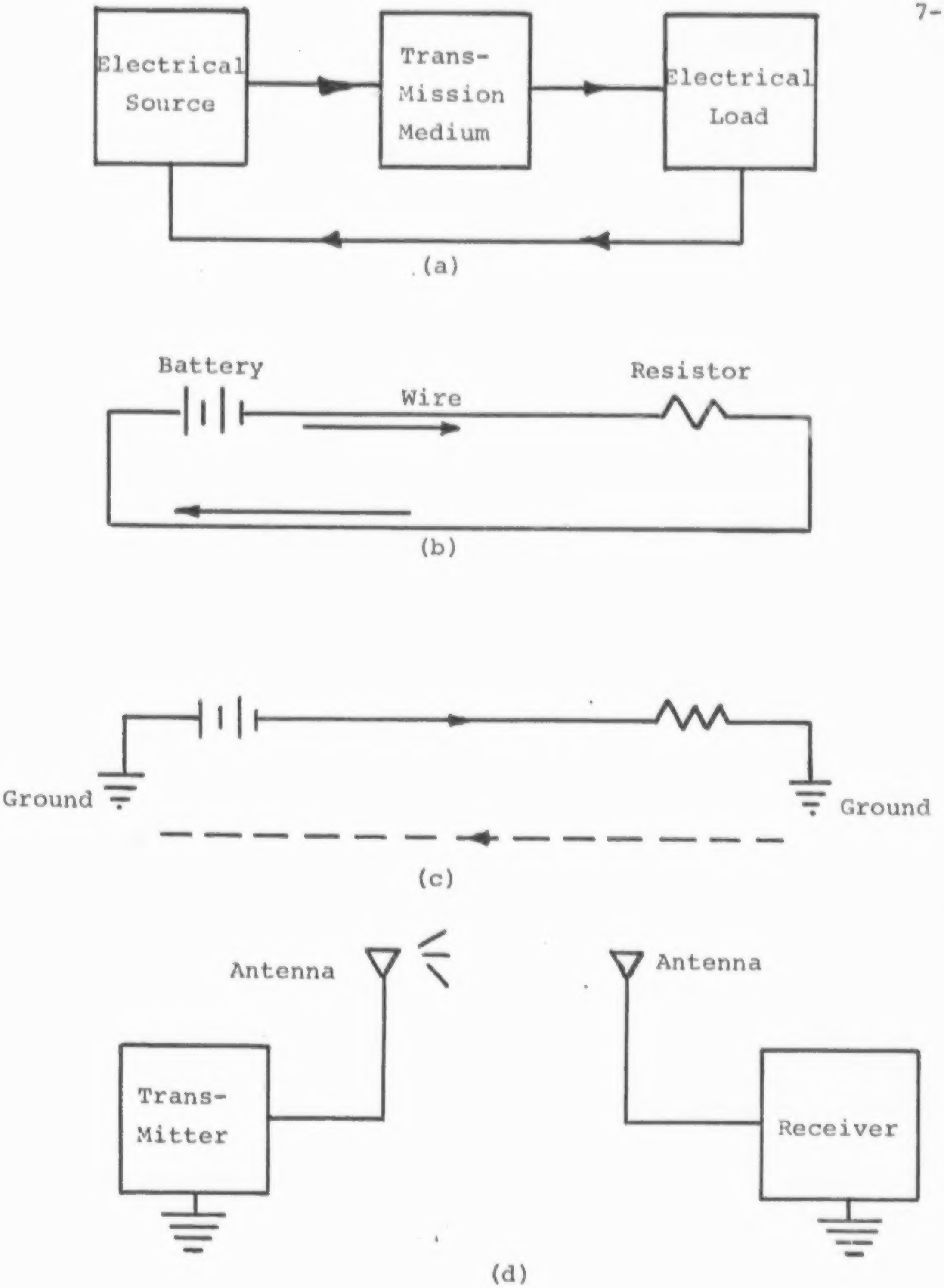

Electrical Source
Trans-Mission Medium
Electrical Load
(a)
Battery
Wire
Resistor
(b)
Ground
Ground
(c)
Antenna
Antenna
Trans-Mitter
Receiver
(d)

Figure 7-1

Electrical Transmission Paths

"ground" though it may be insolated from the earth. In these, individual wires form one path, and the common metal object, which is the tie point, forms the other. Ground connections to the earth, in such cases, are to prevent differences in electrical potential from building up with consequent shock or spark hazard.

Wireless systems also provide a return path through the earth, as shown in Fig. 7-1(d). Here the combination of radiation losses in the air, directivity losses (the portion of the power lost because it is radiated in directions which the receiving antenna cannot pick up) and poor earth conductivity make it necessary to provide a relatively large amount of power at the transmitting antenna in order to receive even a tiny fraction of that power at the receiver.

There are losses in wire transmission systems too, due primarily to power dissipated in the electrical resistance of the wire or cable. Long distance systems will require periodic amplification along the distribution path.

7-1.2. Information Flow

Between any two points in a net work, there are three possible ways in which information may be required to flow:

(1) One-way only, always starting at point A and being received at point B (Fig. 7-2(a)). This is called the "simplex" mode and results in the lowest cost system since A requires only a transmitting device and B only a receiver.

(2) Two-way (not simultaneous), in which information can flow from A to B, or from B to A, but not at the same time (half duplex mode Fig. 7-2(b)). Here terminals A and B both must have transmitting and receiving capability and in addition, the system must incorporate means for knowing what is happening

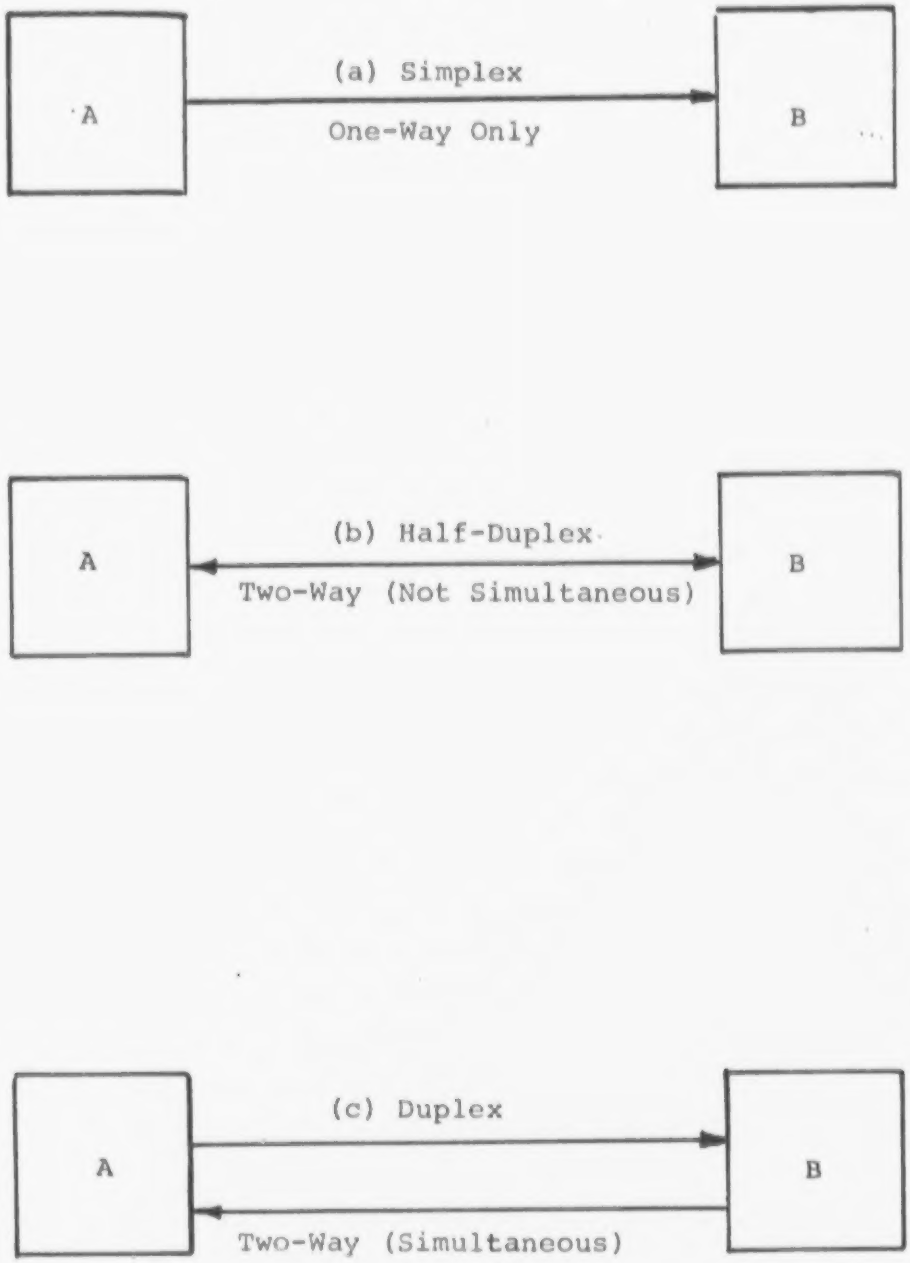

A
(a) Simplex
One-Way Only
B
A
(b) Half-Duplex
Two-Way (Not Simultaneous)
B
A
(c) Duplex
Two-Way (Simultaneous)
B

Figure 7-2

Information Flow Modes

so that no attempt to transmit both ways simultaneously can occur.

(3) Two-way (simultaneous), in which information can flow either way at any time (duplex mode, Fig. 7-2(c)). To permit this, either two separate simplex circuits are used, or the two signals must be separated electrically (either in frequency or time) so that they will not interfere with each other.

Full duplex or half-duplex does not necessarily require that the channels be symmetrical or of equal bandwidth in both directions. A student communicating through a keyboard with a computer, for example, can only send data very slowly, but the return from the computer may contain a high volume of data in a short response time. Thus one channel might be a telegraph or phone line, and the other a wideband video circuit.

7-1.3. Modulation

In Chapter 3, the necessity for modulation was briefly outlined, and the two most common forms, AM and FM, described.

Unmodulated signals, such as the audio output from a microphone or the video output from a video camera, can be transmitted only over short distances without excessive penalty paid in power losses and degradation. A closed-circuit television system confined to a single building or campus might well use direct distribution of audio and video signals, but if the cable distances extend to a few miles or more, the need for amplifiers and similar components will begin to outweigh the efficiencies achieved by modulation.

The choice of what carrier frequency to use, if through-the-air broadcasting is used, may well be dictated by FCC assignment rather than any other criteria. For wire transmission, particularly coaxial cable where the outer conductor shield keeps radiation from occurring, more selectivity can be exercised, both as to carrier frequency and modulation technique.

Here the choice would be determined by:

(a) Type of Wire Link Available - Telephone-line wires, for example, can transmit a bandwidth of about 3 KHz, video coaxial cable up to 30 MHz, and RF coaxial cable up to perhaps 1,000 MHz. The cable costs, however, also rise proportionately.

(b) Bandwidth of Information - This must be less than the carrier frequency. There is no way to transmit a 0-20 KHz high-fidelity orchestra signal or a 4 MHz TV signal over a 3 KHz voice-grade telephone line in real time without distortion and loss of some information.

(c) Requirements of Receiving Device - If, for example, a TV receiver is the end-point, the carrier frequency should logically be that of a standard TV channel, and the modulation scheme also compatible with the receiver's standards. Multiple modulation and conversion normally would be avoided unless other factors override the receiving-end compatibility. (A case in point would be ITFS, described later, in which the FCC dictates 2500 MHz as the broadcast frequency. This requires an added converter at the receiving site to change frequency to a standard VHF TV channel.)

7-1.4. Multiplexing

In many applications, information is generated at a number of locations (e.g., student terminals communicating with a computer). One way of transmitting them, of course, is to provide a separate communications link between each source and destination.

This quickly becomes wasteful, particularly if a single channel can be made to carry all of the generated information. This can often be achieved by multiplexing, which means combining different information signals on the same communications link.

Fig. 7-3(a) illustrates the basic multiplexing concept, with signals generated at locations A, B, C and D being combined onto a single line.

Obviously, multiplexing must be done in such a way that the signals do not interfere with each other and can be separated readily at the receiving end.

Two common techniques used to accomplish this are called "Time Division Multiplexing" (TDM) and "Frequency Division Multiplexing" (FDM) which, as the names imply, separate the individual signals in time and frequency respectively.

The principle of TDM is shown in Fig. 7-3(b). A rotating switch sequentially contacts A, B, C and D and remains at each position for a short time interval. Thus each signal is transmitted serially on the single output line, and each occupies its own time slot so that there is no interference.

If A, B, C or D are continuous signals, it is evident that during the time the switch is not at that location, a portion of the information is prevented from reaching the output. Thus, TDM always results in some loss of information. If the speed of rotation of the switch is made high enough so that it comes around each time before any of the signals have been able to change significantly, the data loss can be made unnoticeable. Thus a critical requirement of TDM is that the sampling rate be high compared to the frequency spectrum of any individual signal. In practice, the rotating switch of Fig. 7-3(b) would probably be an electronic sampling circuit capable of very high switching speeds. Many slow-speed telegraph/teleprinter systems, however, still use rotating electromechanical switches, as described in Chapter 5.

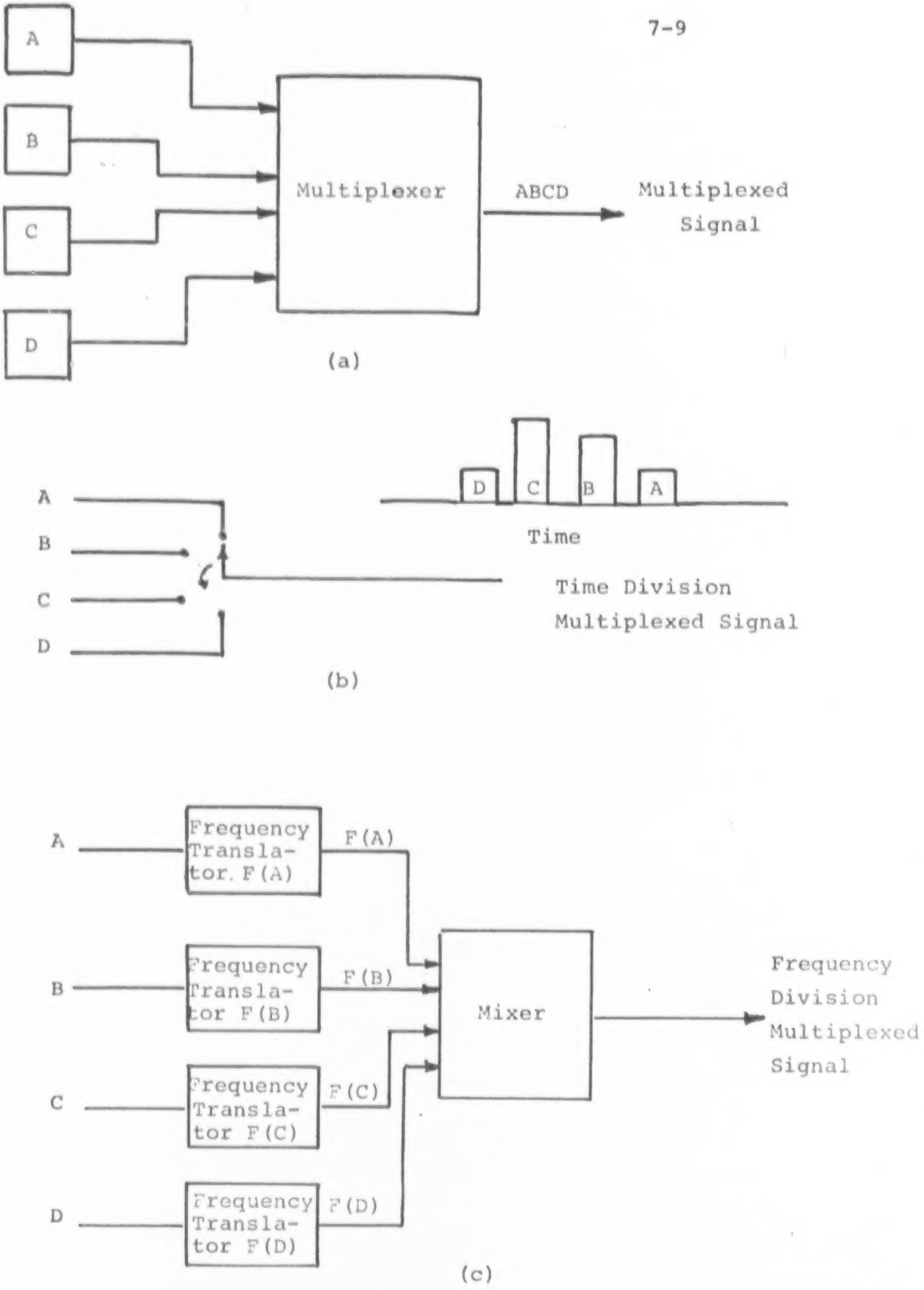

A
B
C
D
Multiplexer
ABCD
Multiplexed Signal
(a)
D
C
B
A
Time
A
B
C
D
Time Division Multiplexed Signal
(b)
A
Frequency Translator. F(A)
F(A)
B
Frequency Translator F(B)
F(B)
C
Frequency Translator F(C)
F(C)
D
Frequency Translator F(D)
F(D)
Mixer
Frequency Division Multiplexed Signal
(c)

Figure 7-3 Signal Multiplexing

FDM, as illustrated in Fig. 7-3(c), takes each signal and translates it to a different frequency band. If A, B, C and D for example were all audio signals with a normal frequency range of 0-5 KHz, for instance, then the frequency translators might add 5 KHz to A, 10 KHz to B, 15 KHz to C, and 20 KHZ to D. Since adding two frequencies together produces a frequency which is their sum (along with a difference frequency and the original frequencies, all of which must be filtered out), the result will be:

F(A) = 5-10 KHZ
F(B) = 10-15 KHZ
F(C) = 15-20 KHZ
F(D) = 20-25 KHZ

These new signals, all of which now occupy a different position of the frequency spectrum, can be mixed together on the same line, and can later be separated by appropriate filters.

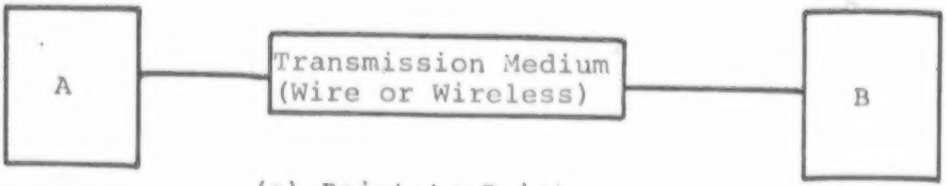
FDM has the advantage, compared to TDM, that no portion of the original information is lost. Its disadvantage is the need for accurate filters, a component whose design is hardly exact and whose characteristics may not be linear. As a result, some distortion of the original information is hard to avoid.

Demultiplexing is the reverse of multiplexing, separating out the individual signals from the composite. All of the illustrations of Fig. 7-3 can be viewed from right to left, with the combined signal being the input and the demultiplexed signals the respective outputs.

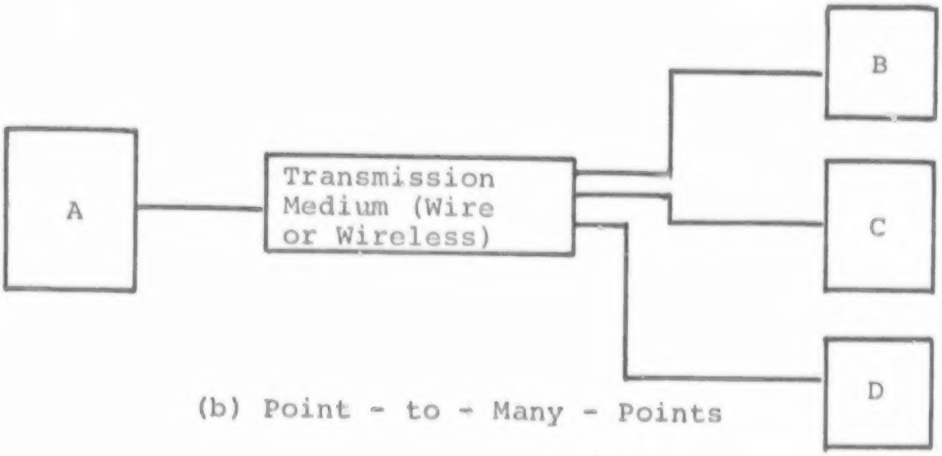
7-2. Distribution Networks

The type of distribution network used is related to the number and location of the receiver/users in the system, and to some extent whether reception must be controlled or not.

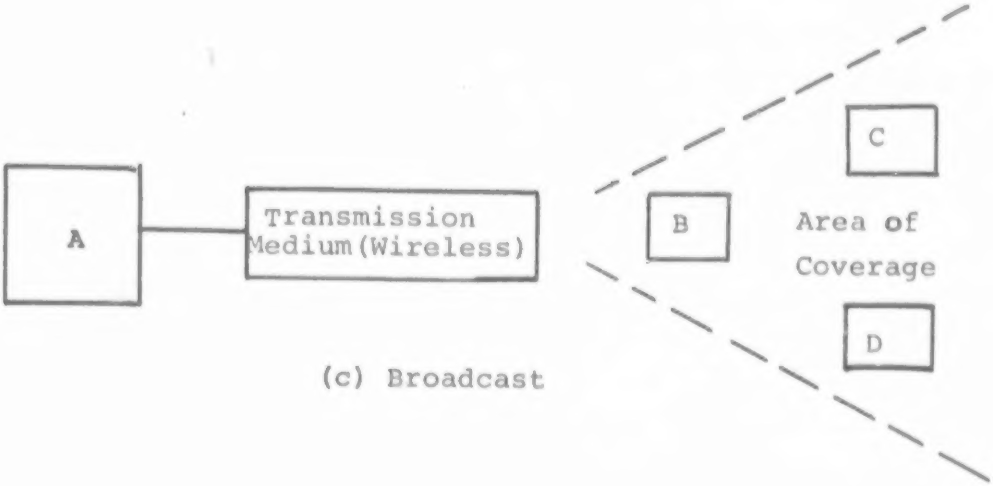
Fig. 7-4(a) illustrates the simplest type of distribution system, termed "point-to-point", where there is only one source


A
Transmission Medium
(Wire or Wireless)
B

(a) Point-to-Point


A
Transmission
Medium (Wire
or Wireless)
B
C
D

(b) Point - to - Many - Points


A
Transmission
Medium(Wireless)
B
C
Area of
Coverage
D

(c) Broadcast

Figure 7-4

Distribution Networks

of information and one using location. A *wired* system would be a direct connection between the two points (neglecting any requirement for amplifiers, modulators, etc.). The *wireless* equivalent would be a *highly directive* beam aimed from a transmitter so that only one receiver in a specific location could receive its signal. (This is a typical *microwave repeater link*, used in cases where cable connection might be too expensive or difficult, such as across a river.)

Fig. 7-4(b) illustrates a "point-to-many-points" network in which information is directed from a single source to a *selected number* of receiving locations. Again the actual paths could be either wire or wireless. An example of the former would be a CCTV system in which a TV program can be sent to a specific group of receiving monitors, possibly under control at the source.

The "broadcast" mode of Fig. 7-4(c) implies a signal which covers a *relatively broad geographical area*. A radio or TV station which might have a strong signal up to a 50-mile radius from the transmitter would be an example. Anyone who possesses a compatible receiver can receive the signal, with no possibility of being able to select or control the number of receivers at any time. If, of course, a non-standard frequency or mode of modulation is transmitted, the potential user is forced to obrain a receiver which is compatible, but the general philosophy of broadcast systems is to maximize, not limit, the audience.

The concept of "cable-casting" has arisen recently, particularly with respect to CATV systems, and it is a *wired* equivalent to wireless broadcasting, in which a locally-generated program is sent over a particular cable channel, and any subscriber connected to the cable system can receive it on his TV set. This is not a retransmission of an over the-air TV signal, but one originated by the CATV operator (or perhaps a local school) within the cable system itself.

Apart from the destinations to be reached, another significant feature of the distribution network is the nature of the path taken. Fig. 7-5 illustrates various routing techniques in common use.

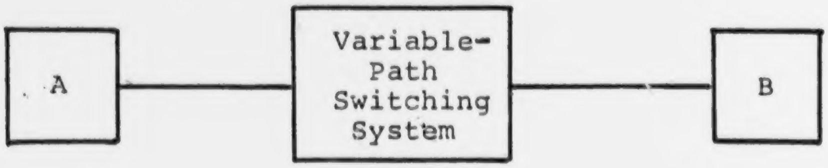
The "switched network", shown in Fig. 7-5(a), is one in which many paths are available between the source A and the destination B. Which particular path is selected at any particular time depends on whether some are being used for other messages. The system will automatically search for an "open" path and route the A-B message on it. At a later time, another path likely will be selected.

The most obvious example of the switched network is the dial telephone system. If someone in New York dials a number in Chicago, his call may go directly to a wire link between New York and Chicago. If, however, these direct circuits are all busy, his call may be routed from New York to Los Angeles, and then from Los Angeles to Chicago. The caller does not know, or care particularly, which route is taken and he is charged the same toll in either case.

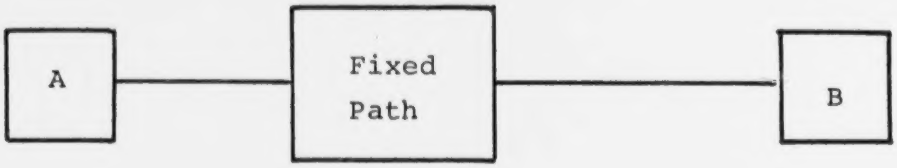
The advantage of the switched network is the ability to "load-share", i.e., seek out and use idle circuits when others are temporarily overloaded, thus smoothing out the peaks and valleys of traffic flow. The cost and complexity of the seeking and switching apparatus, however, reserves this technique for large-scale systems. Further, the diversity of paths carry with them an equal diversity of possible noise and interference.

Fig. 7-5(b) illustrates the fixed-path, "dedicated" connection. This is equivalent to a point-to-point direct link in that, even though a variety of equipment is in the traffic path, the path is always the same. Thus it can be optimized in terms of matching the signal characteristics. Since it is dedicated to only one source and user, however, the 24-hour-a-day cost must be borne by that application and in many cases the cost is high.

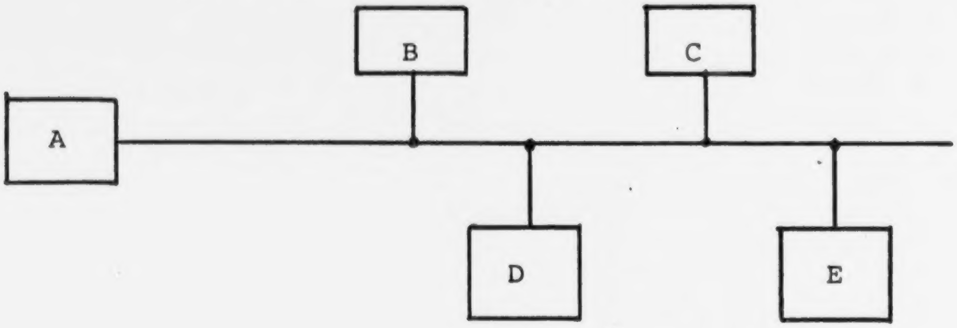
(a) Switched Network


A
Variable-Path Switching System
B

(b) Dedicated


A
Fixed Path
B

(c) Multi-Point (Party Line)



(d) Message-Switching

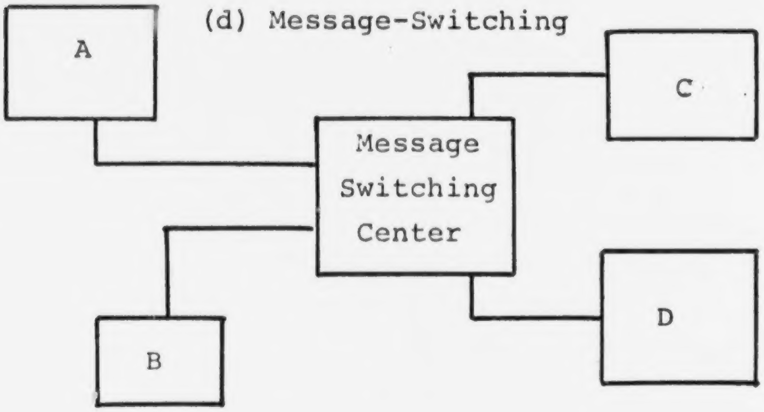

A
C
Message Switching Center
D
B

Figure 7-5

Message Routing Techniques

The party-line type of routing is shown in Fig. 7-5(c) in which one channel carries the same information "down the pipe", and many users can tap in at any location. The number is limited only by whether the taps degrade the main stream of information or cause inteference among users.

A more sophisticated routing technique is the "message switching" approach of Fig. 7-5(d). The message switching center contains storage, address location and computational capability in addition to switching.

As an illustration, both A and B may wish to send a message to C. In each case, the message is coded with an address which identifies C as the recipient. The message center receives both messages and, depending upon the way it is programmed, may:

(a) Immediately send message A-C, followed by B-C

(b) Store both, hold them until more messages for C are accumulated, and then send them all. (Store-and forward mode)

(c) Check message priority and send the high-priority at once, accumulating the lower-priority messages for later transmission.

At present, message switching systems are used primarily on common-carrier and government networks, but they are equally applicable, for example, to a large educational time-sharing computer system where terminals must communicate not only with the computer but also with each other.

7-3. Analog vs. Digital Transmission

7-3.1. Characteristics of Analog and Digital Information

Some preliminary discussion of digital information and coding was provided in Chapter 6, in connection with computer storage and processing techniques.

In a more general way, digital information in electrical form can be described as that information which can be completely defined by a combination of two procedures:

(a) Representation by a number of discrete elements. Although not the only approach, almost all electrical systems limit these elements to either of two possible values. This permits low-cost data processing and communications circuitry, since each circuit need only maintain (or recognize) these two states.

(b) Establishment of a code which translates groups of these two-state elements into equivalent numbers, letters or symbols.

In computer terminology, the two-states are designated "0" and "1" and the elements are called "bits". The rate of transmission of digital information is measured by bits-per-second (bps) and all bits are electrical pulses of equal time duration. Thus, a transmission rate of 1,000 bps means that 1000 bits, each of which can be either a "0" or "1", are sent through the distribution system in one second. Each bit lasts the same period of time (perhaps 1/2 millisecond) and is separated by a period of time (the other 1/2 millisecond) from the next bit.

In data communications, another term is used which is sometimes confused with "bits" and "bps". This is the "baud", an old telegraphy term. A baud is defined as the reciprocal in time of the shortest code element. Bauds and bit rates are equal to each other if two-level signaling is used and all code elements are equal in time. This is true of computer-generated data. In telegraphy, however, some code elements (such as "dashes" in the Morse Code) are transmitted for longer time intervals than others ("dots") and the baud would be different from bit rate. Since it is the reciprocal of the shortest code element, the baud is a measure of the maximum transmission rate. If the shortest element, together with its spacing interval requires one-hundredth of a second, the baud rate would be 100, meaning that up to 100 of these elements could be transmitted per second through the system.

Many common-carrier links are specified in baud, particularly the low and medium speed channels. The decreasing use of telegraph-type codes, however, is resulting in *bit rate* gradually superseding baud as the measure of digital transmission rate.

So far as educational telecommunications systems are concerned, the main categories of information transmitted are *audio*, *video* and *data*. Audio and video are generally *analog*, or continuous, in form (although it is possible to convert them to a series of digital values if this offers any advantage).

Data, on the other hand, is inherently digital in nature, consisting of text (discrete alphabetical letters), numbers and symbolic characters. In the word "AN", for example, the A and N are separate characters and, once coded digitally, make up *all* of the information to be stored or transmitted. If these two letters in digital electrical form are transmitted and recognized properly, there can be no loss of information.

This feature gives *digital transmission* one significant advantage. Analog signals, whether transmitted by wire or wireless carriers, are subject to degradation and distortion from many sources. Some of these are the nonlinearities introduced by such devices as amplifiers (needed to compensate for signal losses) and filters (to block unwanted signals). Others, such as thermal noise generated by random electronic motion, are inherent in the electronic process. In either case, the pertubations make more difficult the task of receiving the analog signal as an exact representation of the original information. The problem can be likened to measuring an exact point on the ruler - with the ruler moving somewhat erratically all the while.

In digital transmission, however, the receiving equipment need only determine which of two states each bit signifies.

This task is much easier than measuring and reproducing a specific analog value on a continuous scale. Further, only very gross perturbations in the transmission system can cause an error in this determination. As an example, attenuation can reduce the amplitude of digital pulses, but an amplifier inserted into the system need only recognize whether each bit is a "0" or "1", and it then can regenerate a clean, high power output signal. This is true even if individual pulses are degraded seriously (but not enough to prevent the "0" or "1" recognition).

The advantages of digital transmission in terms of greater error immunity and simpler switching and multiplexing circuitry are somewhat balanced by the fact that greater bandwidth is required to transmit the same information. Each digital character, since it is coded into a group of pulses representing bits, takes more time to transmit. Consequently, if transmission time is to be conserved, the transmission rate must increase, necessitating increased channel bandwidth.

In spite of this, the greater immunity to error and the direct compatibility with computers make digital transmission more and more popular in communications systems.

7-3.2. Digital (Data) Transmission

7-3.2.1. Parallel and Serial Transmission

Transmission of data coded in digital form involves sending a number of electrical pulses over the communications system. A group of pulses (anywhere from 5-8 depending on the code used) represents a specific character, which may be a number, letter or symbol.

In order to transmit coded characters, it is necessary to arrange them in a way that will allow their reception without uncertainty. Two techniques permit this to be done, and are known as "parallel" and "serial" data transmission.

In parallel transmission, each element of a character has its own communication channel so that the total character is transmitted at the same time. Fig. 7-6(a) illustrates parallel transmission of a 5-bit character. All five bits are transmitted simultaneously on their own lines. Then the next character generated at the transmitter end is sampled and transmitted the same way.

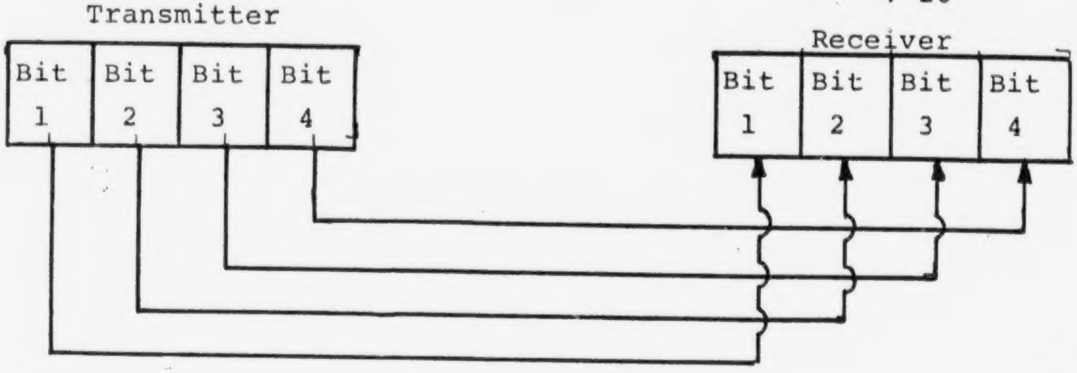
For serial transmission, shown in Fig. 7-6(b), each bit of the character is sent in sequence over a single line. The line must have some means of being switched in turn through all of the bit positions, and the distribution system at the receiving end must have a way of identifying and, if necessary, separating the various elements.

Since serial transmission requires switching through each bit position, it would take 5 switching intervals to transmit the 5-bit character of Fig. 7-6(b). The parallel system of Fig. 7-6(a), on the other hand can transmit the full 5-bit character at once. Consequently, to achieve the same character transfer rate, the serial system would have to switch at a bit sampling rate five times as fast as the character transmission rate of the parallel system.

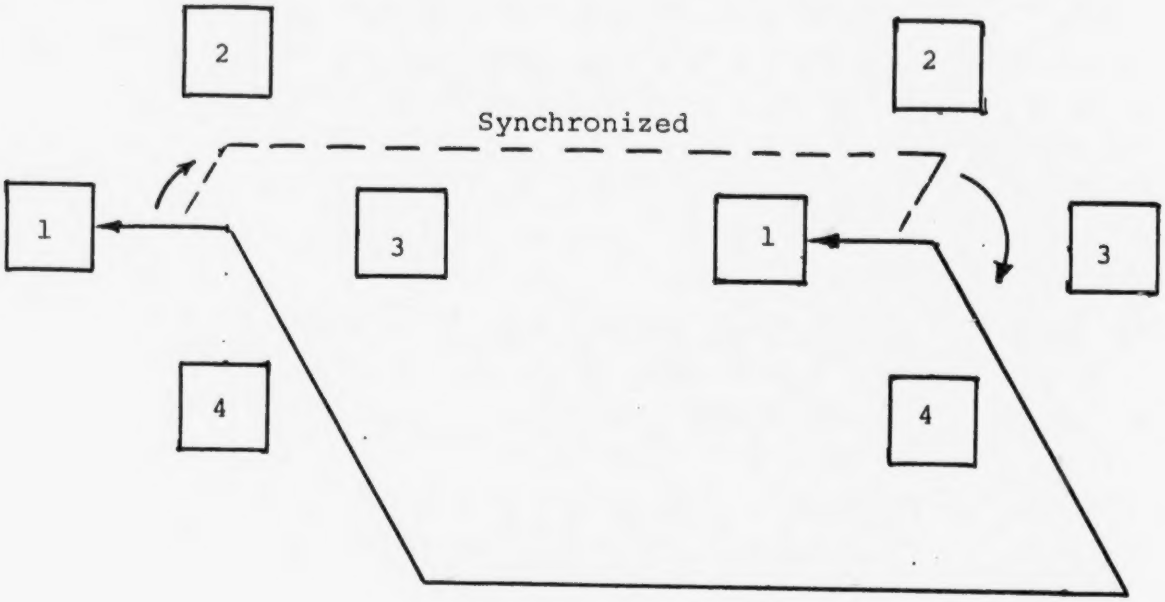
The necessity for high bit sampling rates is one drawback of serial transmission, since these rates involve added expense for switching and synchronizing equipment in addition to requiring broader band, more costly communications channels.

Parallel transmission, on the other hand requires a channel (either a wire pair or, for wireless, a separate frequency band) for each bit in the character. For transmission over any substantial distance, the cable costs become so high as to be prohibitive.

As a result, serial transmission is used for the bulk of data communications, with parallel transmission confined primarily to short-haul systems. Further, most of the digital codes accepted for data communications are designed for serial transmission, since the order of sending each bit in a character is defined precisely.


Transmitter
Bit 1
Bit 2
Bit 3
Bit 4
Receiver
Bit 1
Bit 2
Bit 3
Bit 4

(a) Parallel Transmission


2
Synchronized
1
3
4
2
1
3
4

(b) Serial Transmission

Figure 7-6

Digital Data Transmission Techniques

7-3.2.2. Communications Codes

Table 6-1 illustrated a *generalized* 6-bit binary code which might be used for computer storage, data processing or communications. With respect to communications particularly, however, a few *specific* codes have been standardized to some extent.

Fig. 7-7 shows the Baudot Code, which arose from early Teletype use. It is a 5-level code used only for slow-speed applications and devices (e.g., telegraph, teleprinter, paper tape punches and readers).

Since 5 bits permits only 32 unique code combinations, two of the codes shown "Letters (Lower Case)" and "Figures (Upper Case)" are used as *prefixes* to define which code column of Fig. 7-7 applies at that particular moment.

Fig. 7-8 illustrates the modern USACII (United States American Standard Code for Information Interchange) Code, which is designed for both low and high-speed data transmission, including computer-to-computer communications.

USACII is an 8-bit code which uses 7 of the 8 bits to provide 128 character possibilities as shown in Fig. 7-8. The 8th bit is known as a "parity" bit and is used as an error-checking bit.

Parity checking is a scheme where the 7 bits (in this case) of *each character* are *summed* to produce an "even" or "odd" result. In the summation, "1" bits are counted as odd numbers and "0" bits as even, so that the character "1001101" would produce an "even" result. Another way of viewing it is that if the number of "1" bits is odd the sum is odd, and if the number of "1" bits is even the sum is even.

As these summations are made for each character, a "1" bit or a "0" bit is *generated and placed in the 8th bit position* so that the sum of 8 bits is always an even or odd number. If "even parity" is used, then the 8th bit will make all characters have an 8-bit even sum, *adding a "1" to the 7 bit odd totals* *and a "0" to the 7 bit even totals*.

CHARACTER		IMPULSE POSITION				
LOWER CASE	UPPER CASE	1	2	3	4	5
A	.	●	●			
B	?	●			●	●
C	:		●	●	●	
D	$	●			●	
E	3	●				
F	!	●		●	●	
G	8		●		●	●
H	#			●		●
I	8		●	●		
J	'	●	●		●	
K	(	●	●	●	●	
L	)		●			●
M	.			●	●	●
N	,			●	●	
O	9				●	●
P	0		●	●		●
Q	1	●	●	●		●
R	4		●		●	
S	BELL	●		●		
T	5					●
U	7	●	●	●		
V	;		●	●	●	●
W	2	●	●			●
X	/	●		●	●	●
Y	6	●		●		●
Z	"	●				●
LETTERS (SHIFT TO LOWER CASE)		●	●	●	●	●
FIGURES (SHIFT TO UPPER CASE)		●	●		●	●
SPACE				●		
CARRIAGE RETURN					●	
LINE FEED			●			
BLANK						

PRESENCE OF ● INDICATES MARKING IMPULSE
ABSENCE OF ● INDICATES SPACING IMPULSE

Figure 7-7

Baudot Code

b_7 b_6 b_5						0 0 0	0 0 1	0 1 0	0 1 1	1 0 0	1 0 1	1 1 0	1 1 1
BITS	b_4 ↓	b_3 ↓	b_2 ↓	b_1 ↓	COLUMN → ↓ROW	0	1	2	3	4	5	6	7
	0	0	0	0	0	NUL	DLE	SP	0	@	P	`	p
	0	0	0	1	1	SOH	DC1	!	1	A	Q	a	q
	0	0	1	0	2	STX	DC2	"	2	B	R	b	r
	0	0	1	1	3	ETX	DC3	#	3	C	S	c	s
	0	1	0	0	4	EOT	DC4	$	4	D	T	d	t
	0	1	0	1	5	ENQ	NAK	%	5	E	U	e	u
	0	1	1	0	6	ACK	SYN	&	6	F	V	f	v
	0	1	1	1	7	BEL	ETB	'	7	G	W	g	w
	1	0	0	0	8	BS	CAN	(	8	H	X	h	x
	1	0	0	1	9	HT	EM	)	9	I	Y	i	y
	1	0	1	0	10	LF	SUB	*	:	J	Z	j	z
	1	0	1	1	11	VT	ESC	+	;	K	[	k	{
	1	1	0	0	12	FF	FS	,	<	L	\	l	¦
	1	1	0	1	13	CR	GS	-	=	M	]	m	}
	1	1	1	0	14	SO	RS	.	>	N	^	n	~
	1	1	1	1	15	SI	US	/	?	O	_	o	DEL

Figure 7-8

USAC II Code

When the data has been transmitted and received, a circuit in the receiving equipment will check to see if, indeed, the sum of each 8 bits is even. If so, the character is assumed correct and if not, a transmission error will be noted.

This scheme will detect many errors but not all. If the parity sum is odd, then an error must have occurred since the received 8-bit character differs from that sent. If, however, two "1" bits of a character are changed to "0" bits, the sum remains the same, even or odd, as before. Thus, compensating errors are not detected by parity checking.

A large percentage of transmission errors, however, are caused by short electrical transients which may affect a small group of characters. Even the detection of only one parity error in the group can serve to call attention to the possibility that the data may be suspect. Some systems automatically request a second transmission in that event.

The parity feature, therefore, has some value and can be incorporated at relatively little extra expense.

Most computer and terminal manufacturers today are designing for compatibility with USACII so far as the device-to-device communications are concerned, even though a computer may use a different code in its internal processing.

7-3.2.3. Modems

The term "modem" is a contraction of "modulator/demodulator", and refers to equipment that changes the form of electrical information to best match the communications and distribution system that will be used. (The Bell System uses the term "data set" instead of modem, and this has also gained acceptance, so that the two terms are used interchangeably.)

When digital information, in the form of a sequence of pulses, is to be transmitted over a voice-grade telephone line, certain inherent incompatibilities exist, since the telephone network is designed primarily for analog voice signals.

As one example, "noise" or transients on a phone line are not uncommon, but they will not generally distort a voice conversation so badly that it cannot be understood. These same transients, however, can introduce many errors into a serial train of pulses and possibly render the data completely useless.

Consequently, it has been found necessary to modulate the pulse train by converting it to an analog signal which carries the same information as the pulse train but can be transmitted over the phone line more conveniently. At the receiving end, a matching modem demodulates the analog signal back to the original form.

Many techniques are employed by modems, depending upon the required rate of data transmission, and whether optional features such as error checking are desired. One of the simplest schemes is "frequency shift keying" (FSK) in which a digital "1" shifts a carrier frequency to one value, and a "0" to a second value. As an example, a carrier frequency might be 2000 Hz, which is a good frequency for voice-grade lines. A "1" bit would cause the frequency to shift to 2100 Hz, while a "0" would shift it the other way to 1900 Hz. At the receiving end, the 2100 Hz and 1900 Hz "bursts" would be reconverted back to 1's and 0's.

Modems are available from both telephone companies and independent manufacturers, in a wide variety of data transmission rates. (See Chapter 8 for more detailed data.) Prices average about $1 for each bit-per-second, as a rule of thumb.

Standard, dial-up phone lines can be used to transmit up to 2400 bps with relatively error-free results, and up to 4800 bps with specialized techniques for minimizing and detecting erros. Above this, a "dedicated, conditioned" line may permit data rates to perhaps 9600 bps, and requirements in excess of that necessitate a broadband, rather than voice-grade, communications link.

There are now under development *all-digital* wire communications networks in which the characteristics of the cable, switching centers, etc. are specifically designed for *digital data communications*. These, when available would require *no modem equipment*.

CHAPTER 7 - BIBLIOGRAPHY

1. Cronin, F.R., "Modems and Multiplexers - What They Do for Data Communications", Data Processing Magazine, Nov. 1970

2. Murphy, D.E., and Kallis, S.A., Jr., "Introduction to Data Communications", Digital Equipment Corp. handbook, 1968.

3. O'Hare, R.A., "Technology Profile: Modems & Multiplexers", Modern Data, Dec. 1970.

4. Riezenman, M.J., "Data Communications; The Medium and the Message", Special Report, Electronic Design, April 26, 1969.

CHAPTER 8 - WIRE CARRIERS

Early analysis of the possible uses of electricity focused on how electrical energy could be transferred from one location to another. It was found that the metallic elements, in general, offered low resistance to the flow of electrical current. This meant that less power is required at the source to force a significant current flow, and also less power is dissipated along the metallic path itself than for most other materials.

These characteristics, plus the mechanical strength of metals, and their relatively low cost (particularly copper and aluminium) presented an ideal combination for the conduction of electrical energy. As a result, the electric utility industry was born, and a vast network of wire and cable was developed to transfer power from generating sources to users.

With the invention of the telegraph, and later the telephone, wire began to be used for the transmission of information rather than raw power, and a second network, designed primarily for telecommunications, came into being.

In the field of electrical power transmission, metallic conductors remain the only carrier used to any significant extent, since in wireless transmission most of the power radiated is dissipated in space. So far as information transmission is concerned, however, wireless techniques have, since the advent of radio, grown to be a major competitor to wire carriers, since the criterion is receipt of an accurate representation of the original information, rather than receipt of large amounts of power.

8-1. Types of Wire Communications Circuits

Wire communications circuits can be classified by the physical characteristics of the wire itself, or by the kind of information they are designed to transmit. In the latter case, three major categories are commonly used:

(a) Low-speed lines - these include all lines whose bandwidth capability is below that sufficient to carry a human voice intelligently. Telegraph and teletypewriter communications constitute the main applications for this category with data rates of up to perhaps 150 bits per second.

(b) Medium-speed lines - this category, also termed "voice-grade" includes lines which do have the bandwidth for human voice transmission, whether or not they are actually used for voice communications. All of the nation's telephone-line circuits fall into this group, constituting by far the major network in the U.S. and, indeed, the world. Typical bandwidth of a voice-grade line is 300-3500 Hz, which means that both low frequency information and also information above 3500 Hz (but still in the audio range) cannot be communicated without severe distortion. With an appropriate modem and special conditioning, digital data up to about 10,000 bps can be transmitted over a voice-grade line.

(c) High-speed lines - these include every channel whose bandwidth is greater than that of a voice-grade phone line. Terms such as "wide-band" and "broadband" are also used interchangeably to signify high-speed communication circuits.

Physically, simple wire pairs are used for most low and medium-speed circuits. For very short distances, individual wires may be connected on a point-to-point basis, but for longer distances, multi-conductor cables are generally used. These contain a number of pairs of wires within the same jacket and braided metallic shield. Cables are available with anywhere from a few pairs up to hundreds of pairs, depending on how many individual circuits are needed.

Many circuits use a "twisted-pair" configuration in which the two insulated wires are twisted around each other throughout their length. This is to minimize unwanted interference, since the electromagnetic fields set up around the wires tend to cancel each other out.

For any substantial communications distance, wire pairs are limited to frequencies below one or two MHz. One reason for this is the increased power losses for higher frequencies. A second is the so-called "skin-effect". As the frequency of the electrical current increases, more and more current flows around the surface of the wire, rather than being distributed uniformly throughout its cross-section. This not only results in effectively wasting most of the conductive material, but also increases the possibility of radiating signals outside the wire, much as an antenna does.

Thus, for any high-frequency transmission, starting with the video range, coaxial cable is used. In the coaxial configuration, a solid copper inner conductor is surrounded by insulating material which maintains constant spacing to a cylindrical braided copper outer conductor. A protective insulating jacket covers the entire assembly.

With this geometry, the electromagnetic fields are maintained entirely within the cable itself. The outer conductor is almost always "grounded" and thus serves as a shield, both to prevent pickup from outside the cable, and to restrict radiation from within.

Many types of coaxial cable are available, designed for different frequency ranges, underground or aerial wiring, necessity to bend around sharp corners, etc. In general, the larger the cable diameter the greater its bandwidth capacity.

Video coaxial cable is capable of transmitting a bandwidth from 0-30 MHz. Radio-frequency (RF) coaxial cable is available to carry signals up to perhaps 1,000 MHz with tolerable attenuation and power loss.

8-1.1. Private vs. Leased Lines

For those telecommunications systems entirely within a user's facility (e.g., a school building or the campus of a college), the communications lines generally will be installed privately, as part of a user-owned facility.

When longer distances are involved, however, the practicability of privately owned lines decreases sharply. If, for example, a school district wishes to interconnect ten schools as part of a closed-circuit TV system, the lines may have to cross many municipal jurisdictions and rights-of-way. Simply to get permission may be too time-consuming and expensive, let alone actually stringing poles or digging conduit through a sizeable geographical area.

In these cases, the "common carrier" companies offer an alternative in terms of leased communications channels. The common carriers (the term "carrier" in this case refers to the companies, rather than the technique for sending electrical signals) are companies whose business it is to provide communications facilities to the public. They are generally regulated monopolies, since their operations impact the public so directly.

The best known common carriers are the telephone companies, with AT&T (the Bell System) owning about 80% of U.S. telephones, and General Telephone and Electronics (GT&E) and a host of smaller companies the remainder. Western Union is the other major common carrier, specializing in telegraphic and data communications services.

Table 8-1 outlines the types of leased lines available from the Bell System. In many cases, Western Union offers comparable channels.

For almost all facilities, the choice is available between switched-network or private, dedicated channels. As noted in Chapter 7, with the switched-network, the path the signal takes

Service	Switched or Private	Capability	Applications (Typical)
TWX (now W.U.)	S	Narrow band, to 150 bps.	telegraph, teletype
Series 1000	P		
Series 2000	S	Voice band, medium speed	voice (3 KHz bandwidth)
Series 3000	P		computer-to-computer (up to 10.8Kbps) computer-to-terminal (up to 10.8Kbps) terminal-to-terminal (up to 10.8Kbps)
Series 4000	P	Voice band, special conditioning	facsimile, telephotograph
Series 5000 (Telpak, C,D)	S	Wideband, high speed, to 230.4Kbps in increments	All high speed data communications above 10.8Kbps
Series 6000	P	Voice band	transmission of audio program material to AM, FM, TV studios
Series 7000	P	Video band, increments of 6 MHz	Transmission of video, TV, ETV
Series 8000	P	Wideband, to 50Kbps	Private line high-speed communications
Series 10,000	P	Voice band	Interconnection to private microwave systems
Series 11,000	S	Wideband, 50 or 230.4Kbps	Different users may share the same channel

TABLE 8-1

Available AT&T Communications Links

is impossible to predict. This leads to a much greater possibility of changing electrical characteristics, noise, interference and distortion. If these can be tolerated, costs are generally lower.

Private lines, since they are dedicated to a single user, must be leased on a 24-hour-a-day basis. If the anticipated usage is low, the cost is generally prohibitive.

Special conditioning is available on voice-grade private lines, which in effect means the electrical characteristics are optimized for the expected type of signals.

Table 8-2 lists typical costs to lease a private, low-speed line. Costs may vary from state to state, since the applicable tariffs must be approved by each state's public utility commission. From Table 8-2, the cost of a 100-mile, Type 1002 line would be $140/month. If a teleprinter terminal were at each end, and the terminals are assumed to rent for $100/month each, the operating cost of this communications link would be $340/month. It can be seen that for an education computer-based system, if the distances were long and the number of terminals sizeable, the communications cost would be a major financial undertaking.

If a voice-grade, medium-speed line is required, Fig. 8-1 illustrates typical toll charges for the dial-up, switched network. These charges, depending on distance and time of day, vary from a low of $3/hour to as high as $27/hour. The advantage, however, is that only the time used is paid for.

In contrast, Table 8-3 lists typical costs for a private voice-grade line. The cost per hour is less when amortized over a 24-hour-per-day, 30-day-per-month interval, but the line must be leased for the full month and if only in actual use a few hours, the cost per hour of use could be high. Private lines, obviously, require a minimum usage threshhold to be practical.

Table 8-4 shows the typical lease rates for a high-speed line, in this case capable of carrying up to 50,000 bits per

Line Type	Data Rate (bps)	Distance (miles)	Typical Cost ($/mi./mo.)
1002	55	0-100	1.40
1002	55	100-250	0.98
1002	55	250-500	0.56
1002	55	500-1000	0.42
1002	55	Over 1000	0.28
1005	75	0-100	1.54
1005	75	100-250	1.08
1005	75	250-500	0.61
1005	75	500-1000	0.46
1005	75	Over 1000	0.31
1006	150	0-100	1.75
1006	150	100-250	1.23
1006	150	250-500	0.70
1006	150	500-1000	0.53
1006	150	Over 1000	0.35

TABLE 8-2

Typical Lease Rates for a Low-Speed Private Line

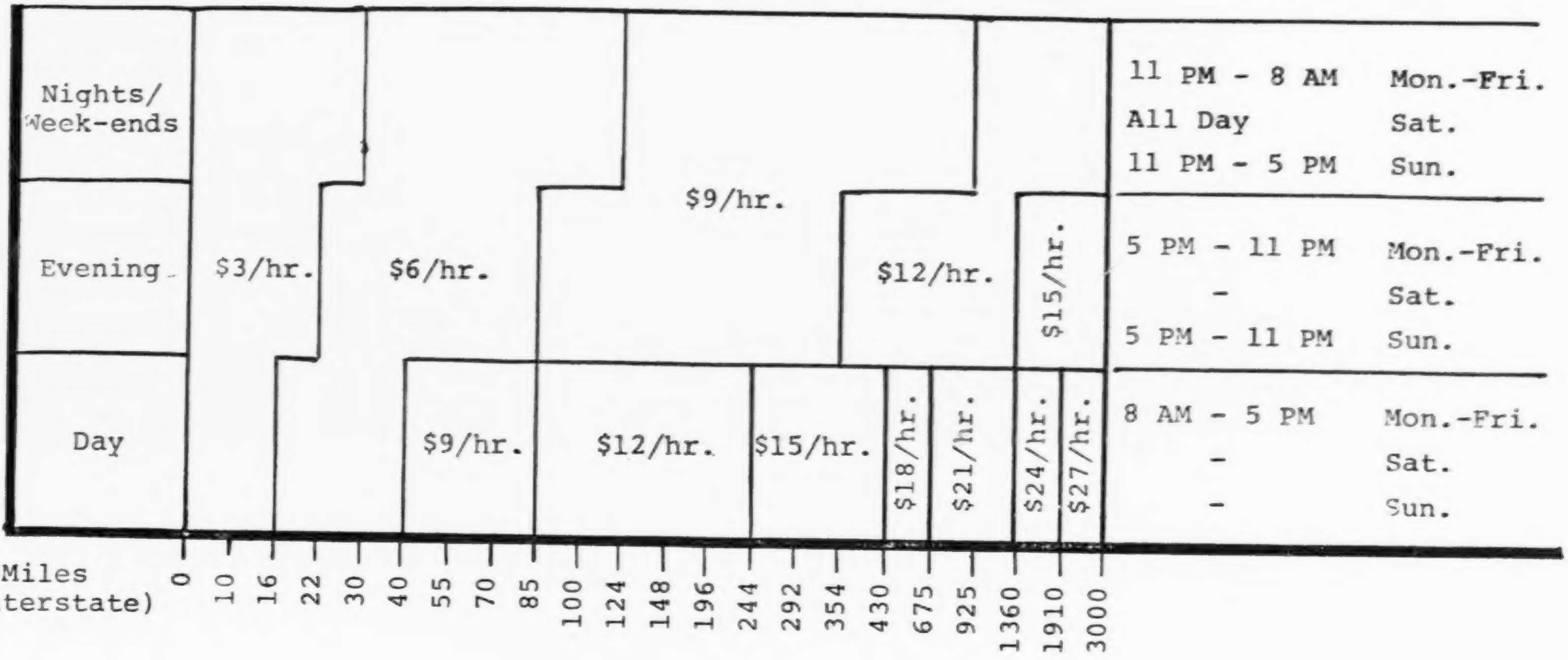


Figure 8-1

Toll Charges, Telephone Dial Network

Line Type	Distance (miles)	Typical Cost ($/mi./mo.)
3002	0-25	3.00
3002	25-100	2.10
3002	100-250	1.50
3002	250-500	1.05
3002	Over 500	0.75

TABLE 8-3

Typical Lease Rates for a Voice-Grade (Medium-Speed) Private Line

Channel Type	Data Rate (bps)	Distance (miles)	Typical Cost ($/hour)
Dataphone 50	50,000	0-50	30
Dataphone 50	50,000	50-150	48
Dataphone 50	50,000	150-300	75
Dataphone 50	50,000	300-600	105
Dataphone 50	50,000	600-1200	135
Dataphone 50	50,000	1200-2000	165
Dataphone 50	50,000	2000-3000	195

(Note: Service provided only between Chicago, Los Angeles, New York and Washington, D.C. Users outside these cities can tie in with a 5000 or 8000 channel.)

TABLE 8-4

Typical Lease Rates for a High-Speed Line second. This is the equivalent of about 12 voice-grade lines, and the rates, compared to Fig. 8-1, are in the order of 7-10 times as high as a single voice line.

It is interesting to note that even this high-speed line falls far short of the bandwidth necessary to carry one TV channel. The 6 MHz required in that case is the informational equivalent of some 2000 voice channels of 3 KHz each. Thus, video information can be sent over the voice network only by slowing down the transmission rate, which requires storage on tape and playback at a very low speed.

Table 8-5 shows the Data Sets (modems) available from the Bell System when digital data must be sent over the voice network. Many other manufacturers offer comparable equipment, functionally interchangeable with the Bell units, on either a purchase or lease basis.

At present, several non-common carrier companies are requesting FCC authorization to construct all-digital communications networks which would be designed only for data transmission. The future availability of such service will eliminate the need for modems.

8-1.2. Advantages and Disadvantages of Common-Carrier Communications Links

There are many advantages that leased common-carrier communications can offer to designers and users of educational telecommunications systems:

(a) No capital investment is required for the communications portion of the system.

(b) Almost any point in the U.S. either is served by, or accessible to, a common carrier.

(c) There is unlimited flexibility to expand (or contract) the system as necessary, again without a capital expenditure.

Series	Transmission Mode	Band-width	Speed	Type Sets	Maximum Speed, bps	Facility	Commonly Used Terminals
100	Serial	N	Low	T-R	150	DDD (TWX) PL	Teletypewriter
100	Serial	V	Low	T-R	300	DDD PL	Teletypewriter; low speed CRT
200	Serial	V	Medium	T-R T-R	4,800 10,800	DDD PL	Medium-speed binary equipment; CRT
300	Serial	W	High	T-R	230,400	PL DDD (Data-Phone 50 service)	High-speed binary equipment; facsimile; computer-to-computer; magnetic tape
400	Parallel	V	Low	T-R T-R	600 75cps	DDD	Medium-speed paper tape systems; card readers
600	Analog	V		T-R T-R		DDD PL	Medical devices; facsimile; telemetry

Note: N = narrow
V = voice-grade
W = wide

DDD = dial network
PL = private line
T = transmit
R = receive

TABLE 8-5

Bell System Data Sets

(d) The time required to integrate the communications links into the system is usually much shorter than if a new privately-owned network were constructed.

(e) Funds for operating a system may be more easily obtained by educational organizations than for constructing one, as there are generally limitations on new plant expenditures.

When these are added to the fact that in many instances, the difficulties involved in constructing a private communications network over a sizeable area simply cannot be met by an educational institution, the common-carrier networks generally win by default if for no better reason.

Although there may be no other choice, the disadvantages of common-carrier communications must be acknowledged and evaluated before any applications can be implemented:

(a) Switched-network communications are susceptible to unpredictable variation in performance characteristics. Private lines are better, but require a high usage factor.

(b) Digital (data) communications facilities are marginal-to-inadequate, since most common-carrier circuits were designed for analog transmission.

(c) Line rental charges are relatively high, making the communications portion of the system a major operating burden.

(d) There is a shortage of broadband channels, which can accept mixed-media signals, such as video, audio and data combined together.

The last item is particularly critical, since the majority of educational systems will have mixed-media requirements, and most particularly will transmit video information which in itself requires broadband communications links.

This expanding need for video transmission has led to particular consideration of new broadband communications networks (BCN's). Closed-circuit television (CCTV) is a form of BCN which has been utilized by schools for many years, but it offers no solution to the problem of distribution. With CCTV, either a privately-owned coaxial cable distribution is installed, or common-carrier cable services are leased. In either case, the limitations noted above are present.

Two more recent hybrid distribution techniques offer great potential for educational systems. The first is Instructional Television Fixed Service (ITFS), a broadcast system in which a special frequency is assigned by the FCC for instructional purposes only. The second is CATV, which is a wired broadband distribution system reaching an increasing number of U.S. homes.

ITFS is described in detail in Chapter 9. The background and potential of CATV are discussed below.

8-2. Broadband Communications Networks

8-2.1. Cable Television (CATV)

The original justification for Community Antenna Television (CATV) is well-known: to bring commercially broadcast television programs to remote or inaccessible areas which could not receive a satisfactory "off the air" signal. In 1948-1949 the first CATV systems were constructed, using strategically located high-gain receiving antennas to pick up broadcast signals, and a coaxial cable network which distributed the signals to each subscriber's TV receiver.

Although first aimed at geographical areas of weak broadcast signal strength, CATV later became popular in metropolitan and suburban locations where broadcast television signals were strong. Among the reasons for this popularity were the desire to have a choice of more programs than were broadcast in the local community and an improvement in picture quality due to elimination of interference from buildings, radiated electrical noise, etc. Table 8-6 illustrates the exceptional growth of CATV between 1952 and 1970. Projections are that by 1980, perhaps 20-30,000,000 homes will be "cabled".

While CATV was growing in number of operating systems, there was a concurrent growth in channel capacity (a CATV "channel" is 6 MHz, consistent with commercial TV standards). From the original 3-5 channel systems, rapid introduction of seven-channel (the maximum number of VHF stations assigned to any single metropolitan area) and twelve-channel (the total number of assigned VHF channesl) systems took place. Currently, many municipal CATV franchise ordinances call for a minimum of 20 channels capacity, and 30-50 channel capacity is foreseen for new systems.

Until recently, CATV systems distributed commercial television programs almost exclusively. In recent years, "local origination" programming has commenced on some systems, prodded partly by the FCC and partly by the system operators' interest in developing local advertising and viewer good will. Even more recently, the concept of "public access" to selected channels is being explored and initiated on a trial basis in a few areas (e.g., New York City). Under this concept, one or more CATV channels are considered as common carriers and are available to all members of the public under appropriate ground rules (limitation of time, usage fees, etc.).

Much has been written about the future use of CATV (now more appropriately termed "cable television" or "broadband cable communications", since the community antenna connotation has largely vanished). The glowing forecasts, in some cases based on dubious economic and technological premises, arise from the following key characteristics of cable television distribution systems:

Year	Operating Systems	Total Subscribers
1952	70	14,000
1953	150	30,000
1954	300	65,000
1955	400	150,000
1956	450	300,000
1957	500	350,000
1958	525	450,000
1959	560	550,000
1960	640	650,000
1961	700	725,000
1962	800	850,000
1963	1,000	950,000
1964	1,200	1,085,000
1965	1,325	1,275,000
1966	1,570	1,575,000
1967	1,770	2,100,000
1968	2,000	2,800,000
1969	2,260	3,600,000
1970	2,350	4,500,000

TABLE 8-6

Growth of CATV

- Although its primary mission is to transmit standard TV programs, each occupying a 6 MHz bandwidth, any channel on the cable is capable of distributing many other kinds of information. A single 6 MHz channel is the informational equivalent, for example, of 1500 telephone voice-grade channels of 4 KHz bandwidth each. Thus many contemplated applications involving a mix of video, audio, and digital signals can utilize the cable "highway".

- The use of shielded coaxial cables for signal transmission requires no utilization of the already crowded broadcast frequency spectrum and therefore no competition against other services for assignment of frequencies.

- System expansion incurs a relatively modest initial cost. A large share of the cost of installing a cable system comes from the physical preparation of cable rights-of-way (either digging underground paths or attaching the cables to existing telephone poles). Once a trench has been dug, the cost of installing a 20-channel cable system is not so much higher than a 12-channel system as to preclude the larger installation if it appears at all reasonable that the spare channels will be used in the future. Once installed, however, the cost of a retrofit expansion is inordinately high. Consequently, many current cable systems are installed with spare channel capacity. These are later available for use at relatively insignificant cost.

- Transmission of signals through the cable, although almost exclusively unidirectional in the past, can be made bidirectional, though admittedly with some cost and effort. The cable itself is bidirectional, but the associated amplifiers are not, so that either reverse amplifiers, with some means of switching, or a full duplicate system, may be involved. In any event the bidirectional capability, which opens the system to a host of new applications, is much more easily achieved via cable than through a wireless broadcast medium.

- Cable television, because of its past and anticipated future growth, reaches a sizeable percentage of the total population of the United States. If it begins to approach the universality of the telephone, it will indeed permit many "mass audience" applications which could not be implemented by broadcast techniques, with its scarcity of frequency spectrum space.
- Cable systems permit communications to a precisely defined, specialized, local audience (sometimes termed "narrow-casting", as contrasted with broadcasting which reaches a large audience but with generalized, "majority-oriented" material). Thus local or specialized interests can be satisfied more easily. If there is two-way communications capability, applications termed "narrow-gathering" (collecting data from a large number of subscribers and sending it over to a centralized processing unit, such as in audience polling) become possible.

CATV System Structure

In a typical CATV system, the broadcast signals are received by specially designed antennas at carefully located reception sites and are processed for introduction into the cable distribution network. The combination of antennas and processing equipment is commonly referred to as the "head-end". The distribution and processing center, which may or may not be at the antenna location, is often referred to as the "hub", where off-air signals and locally originated signals are merged for distribution. A typical head-end is illustrated in Fig. 8-2.

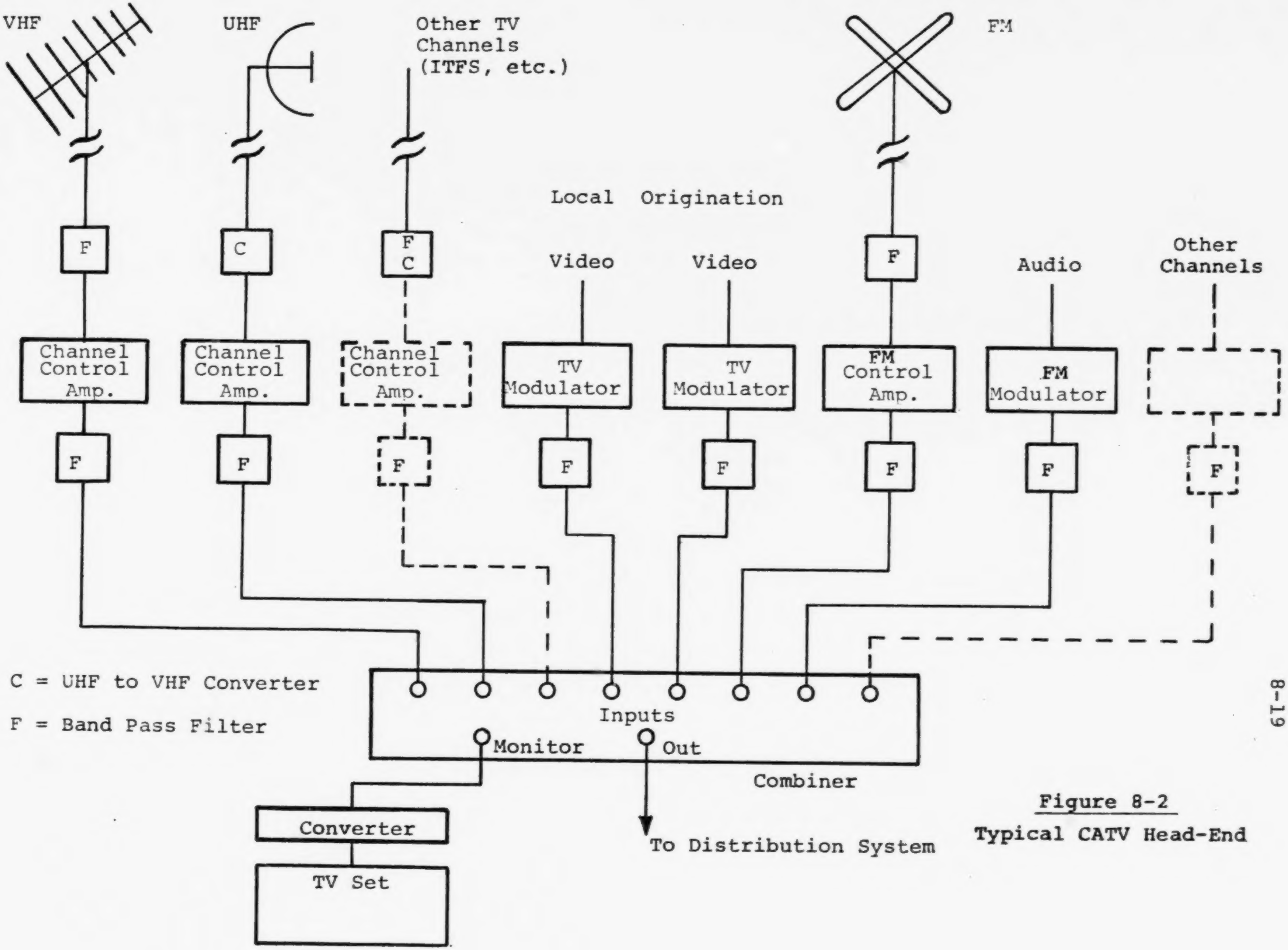

VHF
UHF
Other TV Channels (ITFS, etc.)
FM
Local Origination
Video
Video
Audio
Other Channels
F
C
F C
F
Channel Control Amp.
Channel Control Amp.
Channel Control Amp.
TV Modulator
TV Modulator
FM Control Amp.
FM Modulator
F
F
F
F
F
F
F
F
C = UHF to VHF Converter
F = Band Pass Filter
Inputs
Monitor
Out
Combiner
Converter
TV Set
To Distribution System

Figure 8-2

Typical CATV Head-End

Usually, individual antennas are used for each TV channel to provide maximum gain and directivity. Weak signals may be strengthened by preamplifiers located at the antenna terminals. The output from the head-end, which is the total combination of off-air and locally originated television and FM signals, is carried to the subscriber through special shielded coaxial cable. The cable may be attached to existing telephone and/or power poles or placed underground, either through existing conduits owned by the telephone and power companies or through privately owned rights-of-way. Fig. 8-3 illustrates a typical CATV distribution system.

The main distribution cables are known as "trunk" cables or "trunklines". These branch into secondary "feeder" cables and finally into the subscribers' homes through "drop" cables. All signals experience some attenuation loss in the network, which is a function of the signal frequencies and type of cable used. To offset this loss, various types of "amplifiers" are required to maintain signal level throughout the system. The loss at the higher frequencies is greater than that at the lower frequencies. This requires that the system be "equalized" to compensate for this differential loss. Modern amplifiers have built-in equalizing characteristics.

The coaxial cable used today is capable of carrying bandwidths up to perhaps 1000 MHz (over 160 TV channels) with tolerable performance.

Current state-of-the-art amplifiers, however, can provide flat bandwidths only to about 300 MHz, which theoretically is equivalent to 50 TV channels. Because of practical limitations (such as second-harmonic interference, filtering problems at the lower frequencies, requirement for guard bands, etc.), CATV equipment manufacturers claim in their current designs 20-30 channel capacity for a single trunk cable system. Dual or multiple cables can, of course, increase total channel capacity with essentially no technological limit.

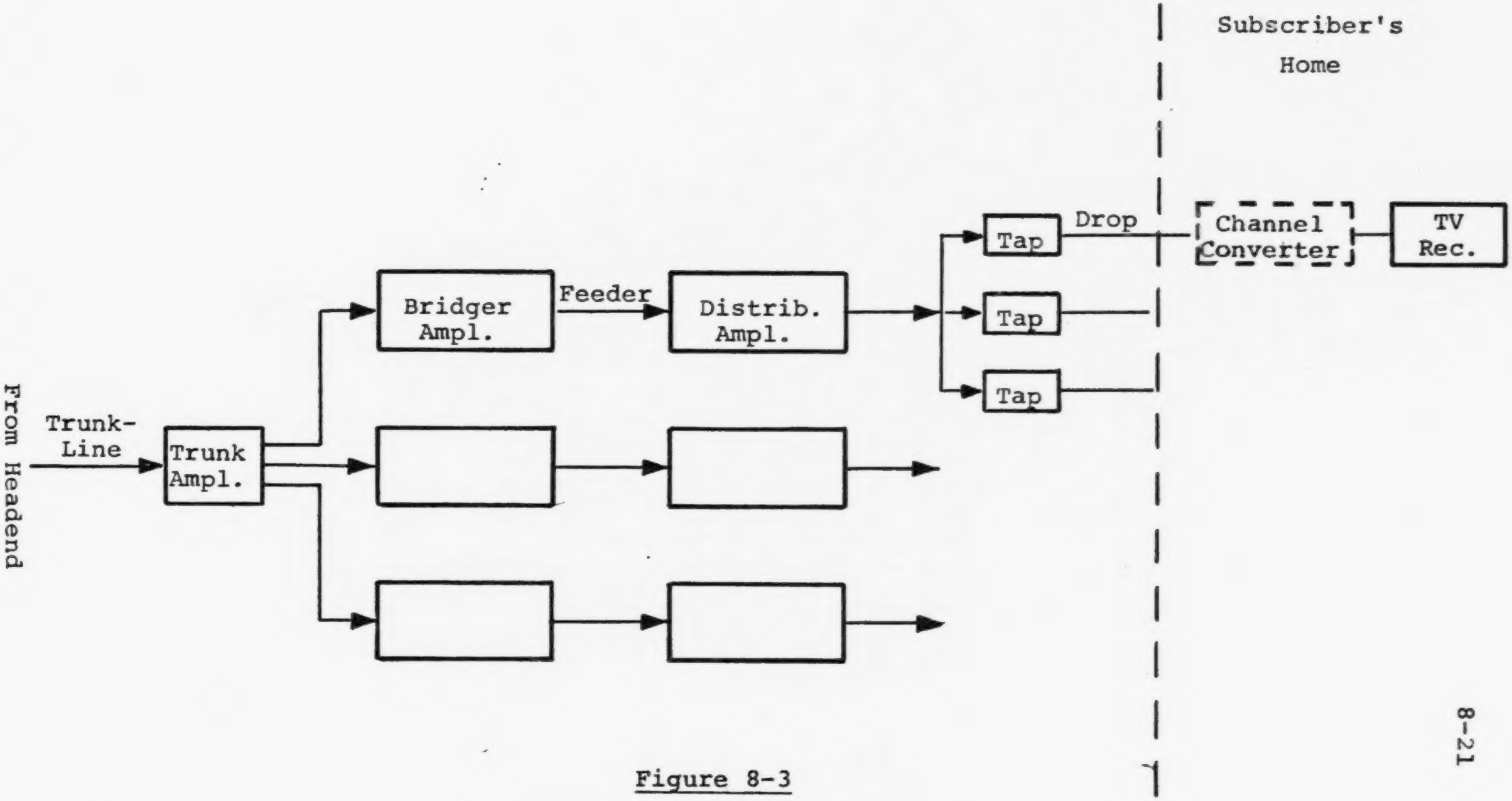

From Headend
Trunk-Line
Trunk Ampl.
Bridger Ampl.
Feeder
Distrib. Ampl.
Tap
Tap
Tap
Drop
Subscriber's Home
Channel Converter
TV Rec.

Figure 8-3

CATV Distribution System

This large number of channels is of key interest to educators, among others. Since commercial TV is limited to 7 broadcast stations in any area, even bringing in non-local stations and "public" stations would probably saturate a CATV system at about 10-15 channels. Any channel availability above that number could be used for educational applications at very low cost. The major constraint is the need for the "students" to have access to the cable network. This access is aided by the practice of providing free CATV connections to local schools, and by the growing number of homes which subscribe to CATV service.

Two-Way Communications Capability

The value of cable distribution systems to education may depend to a sizeable extent upon the feasibility of providing two-way communications capability. This would permit querying and interactive response by the student. Many other non-educational applications also would be enhanced by two-way transmission. Because of this, the FCC has decreed that two-way capability be included in the newer and larger CATV systems.

At least three basic techniques are currently being evaluated for two-way transmission. (It should be noted that here again the amplifiers, which are unidirectional devices, are the major technological problem; the cable itself, inherently bidirectional, offers no barrier to two-way communications.)

The simplest approach is merely to provide a second cable with reversed amplifiers for "upstream" (subscriber to central head-end) transmission. While presenting no technical problem, the cost of this approach is high. Further, for most anticipated applications there may be no need for wide bandwidth capability for upstream operation, since audio or digital messages, rather than video, would probably be utilized. An example would be a school delivering an instructional TV program to students, but permitting only audio querying from students to the originating classroom or studio.

The multiple cable approach, since its technical feasibility is unquestioned, is being used currently where bidirectional capability is a firm requirement.

A second approach, called "discade", is illustrated in Fig. 8-4. Each channel is carried on a *separate* cable at the *same* reduced frequency and sent to an area distribution center serving 24 TV home receivers. From the distribution center, only one cable goes to each home through a channel selector converter. By selecting the channel, the subscriber commands the distribution center to switch the appropriate channel to his home. For *reverse* transmission, other than channel selection, a *separate cable* runs back to the head-end. One converter position is assigned to reverse transmission. The advantage to this approach is that the main cable transmission is at a low frequency, 5-20 MHz, with lower cable loss and less stringent amplifier requirements. The obvious disadvantages are the multiplicity of cables, the complex switching required at the distribution centers, and the waste of unused cable bandwidth capacity.

The third approach uses a form of *frequency division multiplexing*, as illustrated in Fig. 8-5. With this technique the upstream and downstream transmissions are *run through the same cable at different frequencies*. The unidirectional amplifiers are bypassed for reverse transmission by "cross-over" filters. A complementary filter pair is placed both in front and behind each amplifier. Each filter accepts all input frequencies and has two outputs, high-band and low-band. The high-band output (*above 54 MHz*) is connected to the *down*-stream amplifier input, while the low-band (*below channel 2, 54 MHz*) is connected into the *reverse* amplifier.

Thus, frequencies below 54 MHz can be used for reverse transmission, while downstream operation is unaffected, at least in theory. In an actual system, of course, the upstream transmission components may perturb normal operation, and at

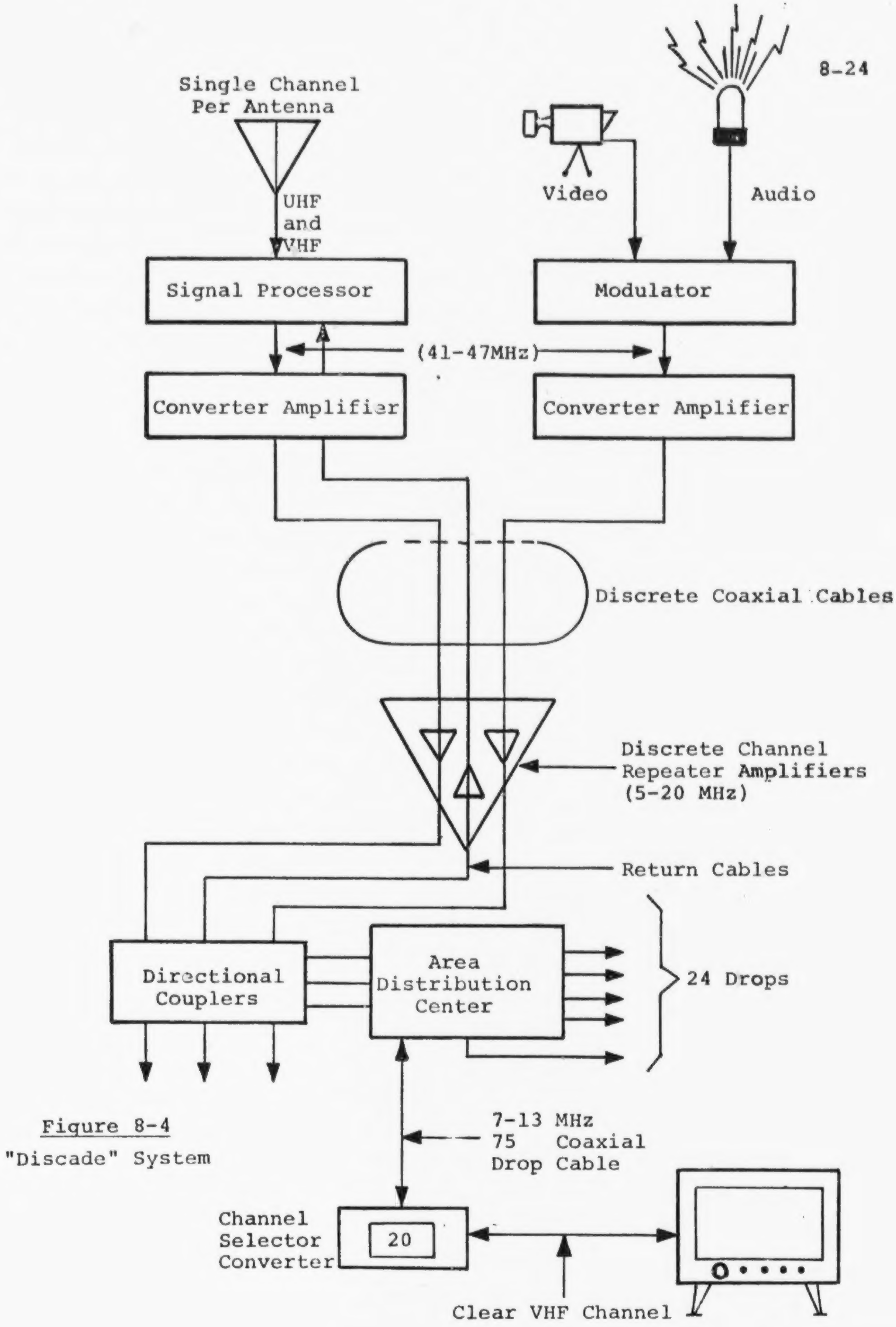

Single Channel
Per Antenna
UHF
and
VHF
Video
Audio
Signal Processor
Modulator
(41-47MHz)
Converter Amplifier
Converter Amplifier
Discrete Coaxial Cables
Discrete Channel
Repeater Amplifiers
(5-20 MHz)
Return Cables
Directional
Couplers
Area
Distribution
Center
24 Drops
7-13 MHz
75 Coaxial
Drop Cable
Channel
Selector
Converter
20
Clear VHF Channel

Figure 8-4

"Discade" System

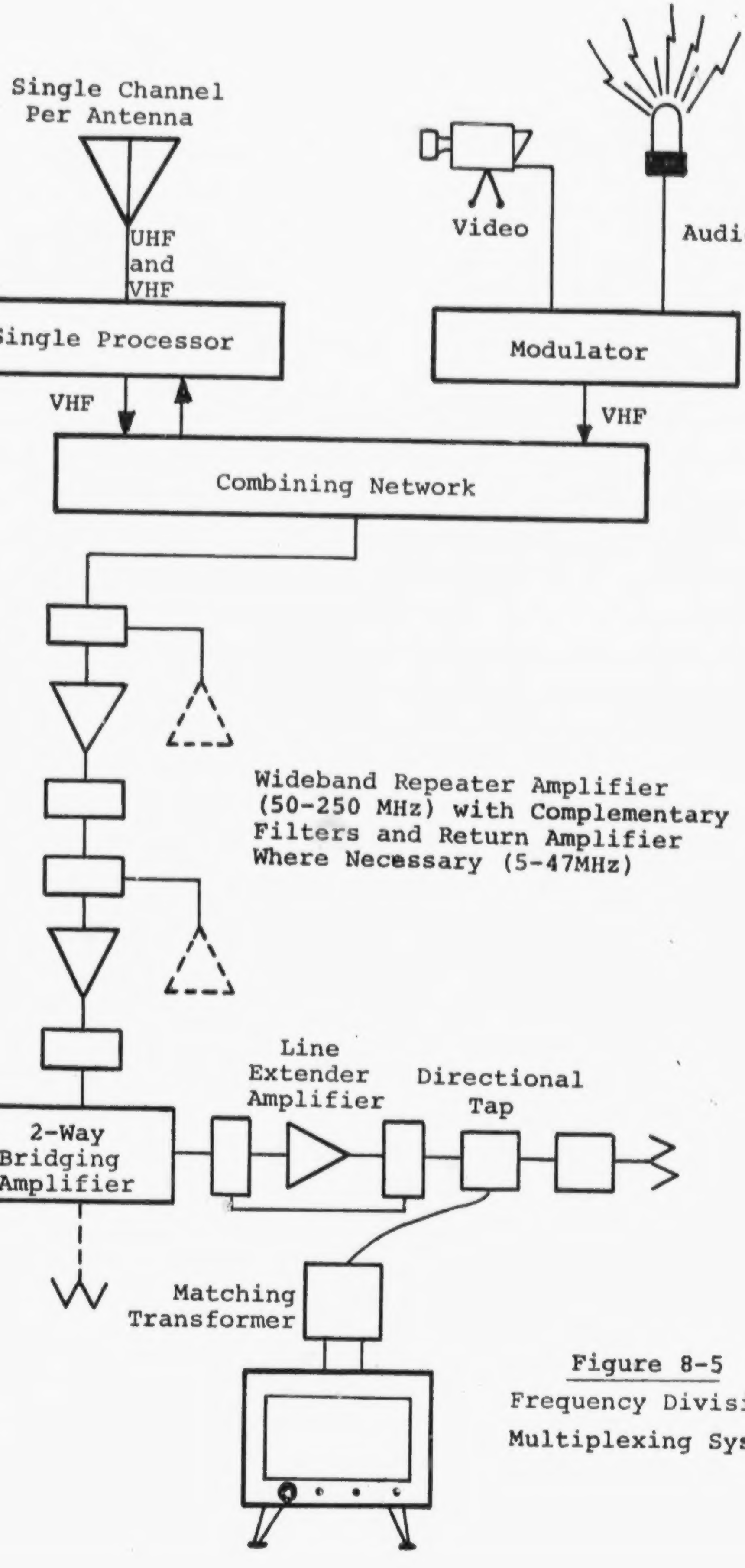

Single Channel
Per Antenna
UHF
and
VHF
Single Processor
VHF
Video
Audio
Modulator
VHF
Combining Network
Wideband Repeater Amplifier
(50-250 MHz) with Complementary
Filters and Return Amplifier
Where Necessary (5-47MHz)
Line
Extender
Amplifier
Directional
Tap
2-Way
Bridging
Amplifier
Matching
Transformer

Figure 8-5

Frequency Division Multiplexing System

this point in time there still remain some technological problems with this approach.

In summation, two-way transmission at this time is well past the conceptual stage, but not yet incorporated into more than a few commercial cable systems. When this capability is more universal, the potential for many new interactive educational applications may be realized.

Program Origination

Another capability being implemented on many CATV systems is the ability to "cable-cast", i.e., originate programs locally and distribute them on spare channels. The CATV system then becomes a more flexible communications network, not relying solely on redistribution of "off-the-air" TV programs.

Local program origination has been conducted on a small scale for a number of years. Initial efforts, designed to keep equipment and program preparation costs at a minimum, were limited to such "automatic" program generating techniques as photographing a time/weather instrument dial, or taking the output from a news or stock market ticker and converting it into an alphanumeric display at the viewer's TV screen. This involved practically no operating costs after the initial modest capital investment.

Some CATV operators extended this by adding inexpensive 16 mm. film camera chains and renting or purchasing films for viewing. "Local event" origination followed, in which events of special local interest (city council meetings, high school basketball, etc.) were televised, with the use of more modern but still low-cost, mobile television camera chains. These were the first instances of fulfilling the oft-expressed claim that CATV could cater to the unique interests of the local community. The FCC has expressed the opinion that this is a function which should be emphasized, and reinforced this stand by requiring local program origination for all cable systems with more than 3500 subscribers.

In addition to the FCC ruling, many municipalities in recent CATV enabling ordinances have specified that a centrally located studio equipped for color television program origination, plus mobile television facilities, be a requirement of the franchise. This has been motivated both by the interest in local event programs and also by growing pressure from educators and school districts who wish to share the facilities for educational programming.

In response, studio equipment has been tailored for the special "cable-casting" market. Comparatively low-cost items (e.g., a $10,000 color camera as compared to a $60,000 network camera) offer near-broadcast quality results. Equipment also has been miniaturized and simplified, with consoles designed to fit into the back of a station wagon, or even in the back seat of a passenger automobile. A compact color television studio package for CATV is available for a total system price of about $65,000.

Use of Cable Systems in Education

To date, the use of cable television facilities for educational purposes has been limited, although the portents for future expansion are encouraging. The primary educational applications have been:

- Increased Availability of Educational/Public TV Channels. By bringing in distant educational and public broadcast channels, and also in some cases converting UHF channels to more popular VHF, CATV systems have provided their viewers with an increased choice of educational programs.
- Reservation of Educational Channels. Most recent city CATV ordinances, in compliance with the expressed objectives of the NEA and local school districts, require reservation (or preemption at a later date if the local educators are not yet ready) of 20% of the total number of channels exclusively for educational use, without charge. Thus four channels of a 20-channel system would

be available for use as the local educators determine. They could generate their own programs or use material available from outside sources.

- Cable Drop to Schools. The CATV operator is generally required to provide free cable drops to each school within the area served by the cable system. Thus, the programs carried are available for viewing at the schools without cost.

- ITFS Interface. Instructional Television Fixed Station (ITFS) service is described in more detail in Chapters 8 and 11. For schools or universities who are operating ITFS, there are cases where CATV systems in the area of reception have agreed to install receiving antennas and converters to translate the 2500 MHz ITFS signals into a standard television channel frequency which is then sent over the cable system to subscribers and local schools. This expands the relatively narrow ITFS coverage.

- Use of Studio and Program Origination Facilities. In some CATV systems educators are permitted to use the studio and program origination facilities without charge at agreed times and with student operator personnel. In others, some charge is levied. A third category is where the CATV operators and the schools have designed a facility satisfactory to both and where both the capital and operating costs are shared.

In all the above cases, the effects, while certainly beneficial, have merely extended the availability or reduced the cost of TV-type or film-type instruction, without adding any new dimension to the instructional and/or educational process. Such new dimensions must await widespread extensions in cable system technology, such as two-way transmission or a mix of audio-visual and digital-graphical data-bank sources of instructional material.

The key feature of the cable system is the abundance of broadband communication channels, available at low cost (once the system has been installed) and free of constraint such as FCC frequency allocations. This, in effect, provides many "highways" which pose a challenge to educators, among others, to use constructively.

CHAPTER 8 - BIBLIOGRAPHY

1. Greenhill, L.P., "Closed Circuit Television for Teaching in Colleges and Universities", Penn. State University, Jan. 1966.

2. Hinkleman, R.M., "Planning a Data Communications System -
Part I: A broad Overview and Basic Concepts - Modern Data, April, 1970
Part II: Common Carrier Facilities", Modern Data, May and June 1970.

3. "Planning Effective Data Communications Systems", Data Processing Magazine, Nov. 1970.

4. Reagan, F.H., "A Manager's Guide to Phone and Data Services", Computer Decisions, Part I, October 1971; Part II, Nov. 1971

Chapter 9 - Wireless Carriers

9-1 Wireless Transmission

In transmitting electrical signals over wire, it is only necessary to provide different wires or cables (adequately shielded) for different messages to avoid any possibility of interference. When the wireless medium is used the problem is more complex, unfortunately. Broadcast signals can and will interfere with each other, particularly if they are at the same or adjacent frequencies, or if one frequency is a multiple of another.

For this reason, the allocation of broadcast frequencies is very critical and, in the U.S., is one of the FCC's most important responsibilities. No signal can be broadcast at any time, on any frequency, without FCC authorization.

When it is realized further that the frequency spectrum currently in use is extremely crowded, with more potential users arising every year, the allocation of this natural resource resembles the problem of providing adequate parking space in the middle of a growing city.

This spectrum crowding results in pressure to use increasingly higher frequencies, and such a trend will continue. The higher frequencies, however, require advanced equipment which in many cases is expensive and, being still in the developmental stage, unreliable.

Educational systems which contemplate wireless transmission must, therefore, select one of the following alternatives:

(a) Use of frequencies reserved for educational use only, such as the 2500 MHz band (described in the ITFS section of this chapter)

(b) Lease of wireless facilities, such as microwave links, from common-carriers

(c) Compete against other applicants in the general broadcast bands, such as AM or FM radio, or VHF or UHF television.

All of these alternatives have been utilized in the past for educational telecommunications systems, and are available today. The third is perhaps the oldest, with universities and colleges operating educational AM radio broadcasting stations for more than 50 years and more recently, FM radio and television broadcast stations. Examples are described in Chapter 10 and 11.

The scarcity of radio and TV broadcast frequencies still available sharply restricts expansion in this direction. This is one reason why other modes of distribution which provide many channels and do not require frequency allocation, such as CATV, are of such interest for the future.

The use of common-carrier wireless facilities may be outside the control of the educational user. A time-shared computer, for example, may use many leased telephone lines to communicate with student terminals. Whether the lines are all-wire links, or at some point use microwave relays is outside the knowledge and the interest of the user, so long as service is maintained.

There are other times when wireless service is specifically required, such as in broadcasting an educational program via communications satellite. Again, however, this is a choice between different links rather than the use of wireless specifically for educational functions.

The area of greatest interest for the future is the band exclusively reserved for educational wireless transmission, the ITFS band. Since the educator will not be competing against other users (only other educators) for the same frequency space, planning on a long-range basis is possible.

ITFS is described in Section 9-2, but some preliminary comment on current use of the electromagnetic spectrum may provide appropriate background.

9-1.1 Use of Electromagnetic Spectrum

Table 9-1 lists the portion of the electromagnetic spectrum used for wireless telecommunications today. The entire spectrum, it should be noted, extends far above the frequencies associated with light waves, but no equipment is yet available which can operate in the upper ranges.

Frequencies at the low end of the spectrum, below the VLF band, are almost never used in wireless systems. The antennas required would be very large, since for efficient transmission and reception the antenna should be an appreciable portion of the "wavelength" of the radiated signal. Wavelength is defined as the inverse of the frequency according to the following:

$$\text{Wavelength (meters)} = \frac{300{,}000{,}000}{\text{frequency (Hz)}}$$

Thus, a frequency of 3000 Hz has an associated wavelength of 100,000 meters, and an antenna of one-quarter wavelength (necessary for good radiation) would be over 14 miles long.

Even for the VLF and LF bands, the wavelength acts as a constraint, which is why long-wave radio is not often used. At the upper end of the LF band, 300 KHz, the wavelength is still 1000 meters long.

Starting with the MF band, however, full use is made of the remainder of the spectrum. The familiar AM broadcast radio band, for example, is allocated between 550-1600 KHz, and is so crowded that frequencies are shared both on a time and geographical basis.

Below the VHF band, from 30 MHz downward, the spectrum is suited to long-distance transmission because radio waves at these frequencies are reflected from the ionosphere (a layer of ionized particles at the earth's upper atmosphere) back down to the ground. Referring to Figure 9-1 (a), a transmitter operating at these frequencies can reach a receiver hidden by the earth's

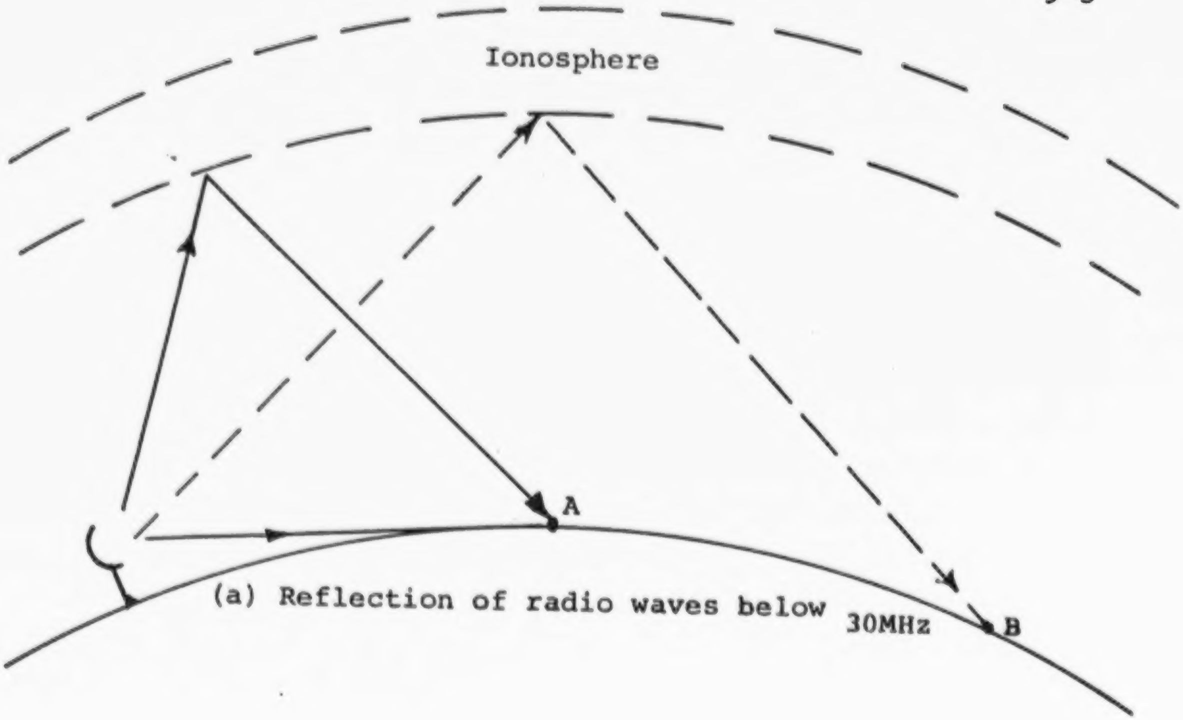
Band Designation	Frequency Range	Wireless Applications
VLF - Very Low Frequency	30-300 KHz	Long-wave radio (rarely used)
LF - Low Frequency	30-300 KHz	Long-wave radio (rarely used)
MF - Medium Frequency	300 KHz - 3 MHz	AM radio broadcast
HF - High Frequency	3-30 MHz	Short-wave radio, radio telephone
VHF - Very High Frequency	30-300 MHz	FM radio broadcast, TV
UHF - Ultra High Frequency*	300-3,000 MHz	TV, ITFS
SHF - Super High Frequency*	3,000-30,000 MHz	Microwave relays
EHF - Extremely High Frequency **	30,000-300,000 MHz	Experimental
- -	above 1,000,000 MHz	Infrared, visible light, Ultra-violet

* - The term "microwave" is generally applied to the 1,000-10,000 MHz region.

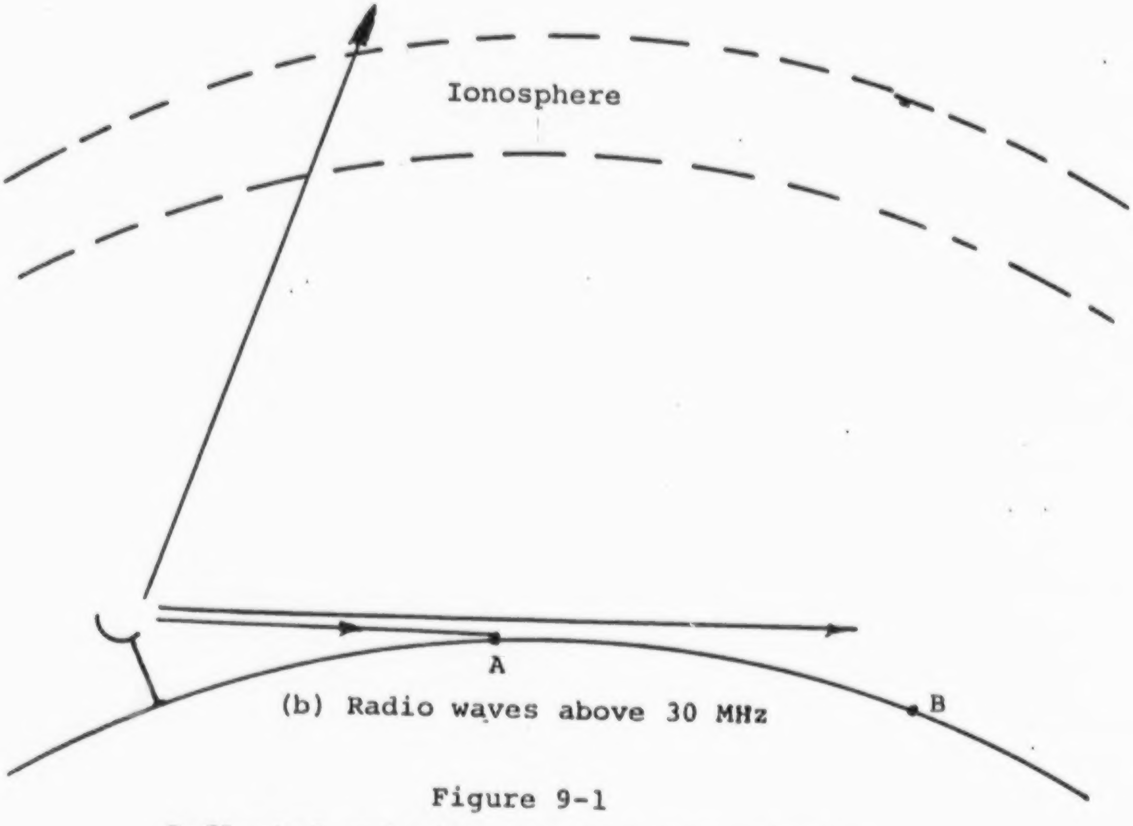
** - The term "millimeter band" applies to the EHF band, but sometimes is used for frequencies above 10,000 MHz.

Table 9-1

Wireless Applications of Electromagnetic Spectrum


Ionosphere
A
B

(a) Reflection of radio waves below 30MHz


Ionosphere
A
B

(b) Radio waves above 30 MHz

Figure 9-1
Reflected and Line-of-Sight Transmission

curvature because of the signals "bounced" off the ionosphere.

At the higher frequencies, however, the ionosphere no longer reflects signals but permits them to pass through as shown in Fig. 9-1 (b). Thus, there is no way for the transmitter to reach receiver B, and its effective range is limited to "line-of-sight", that is, any point which can be seen in a straight line from the top of the transmitting antenna.

This is why VHF and UHF TV transmitting antennas, for example, are located as high as possible, on mountains or the top of the tallest buildings. The height permits maximum audience coverage.

Although line-of-sight transmission is restrictive, it offers one advantage. Two transmitters hidden from each other by the earth's curvature can usually operate at the same frequency without interference. Thus, more stations can be crowded into the same frequency band. As an example, channel 2 on VHF television broadcasts in New York and the same frequency can also be assigned to another TV transmitter so long as it is sufficiently far from New York.

Communications satellites, described later, also operate under line-of-sight conditions but they overlook so much of the earth's surface that they can broadcast over immense distances, effectively negating the limitation of line-of-sight transmission.

With the exception of AM radio broadcasting (whose spectrum is overcrowded even more than others), almost all of the bands of interest for educational systems are in the line-of-sight region. This includes:

(a) FM Radio, broadcast in a portion of the VHF band

(b) Educational and Instructional Television, broadcast on any of the assigned VHF or UHF channels

(c) Instructional Television Fixed Service (described in this chapter) which utilizes the 2500-2690 MHz portion of the UHF band

(d) Microwave relays, which can link various elements of a total communications system.

The coverage of any of these wireless broadcast techniques can be determined by the geographical area within line-of-sight, and by the directivity of the transmitting antenna (whether it is designed to focus the radiation in only one direction).

One point is to be noted. In considering any wireless transmission, the frequencies which have been discussed are invariably the carrier frequencies, which must be modulated by the information to be transmitted. Audio or video frequencies are not radiated directly , due to the low-frequency limitations mentioned.

Thus, a VHF frequency of 300 MHz, for example, might be used as the carrier for a 6 MHz TV signal. The actual video information represents, in this case, 2% of the carrier bandwidth.

If a carrier of 3000 MHz were used, however, 2% of this bandwidth would be 60 MHz. This illustrates that the same percentage of carrier bandwidth can now carry 10 TV channels rather than one.

Because of this, the future use of higher-frequency carriers holds promise of also being able to transmit much more information than we can at present. Optical transmission is an outstanding example of this promise.

9-2 Instructional Television Fixed Service (ITFS)

9-2.1 Description

In July 1963, the FCC allocated the frequency band between 2500-2690 MHz for use by educational institutions and organizations. The band was divided into 31 channels, each with a 6 MHz bandwidth capable of carrying television signals conforming to standard broadcast specifications. The service was labeled Instructional Television Fixed Service or ITFS, and is also referred to as "2500 MHz televison".

ITFS, therefore, is not a new kind of educational or instructional TV, but simply a designated method of transmission which has been reserved for educational use. As such, it complements other methods such as ETV, CCTV, etc. The specific technical characteristics of ITFS, however, and also limitations imposed by the FCC, are sufficiently different from commercial broadcasting to warrant special study. Further, the recent action of the World Radio Conference, July 1971, in allocating the 2500 MHz band for educational purposes, including satellite communications, indicates expanded use of the ITFS spectrum in the future.

The major features and constraints of ITFS are:

- Multi-channel capability is provided. Up to 4 channels of the 31 are available to a licensee to serve a single geographical area.
- The allocated frequency spectrum may be used not only for video, but also voice and data transmission
- The upper 4 MHz of the band, from 2686-2690 MHz, may be used for "reverse" transmission, i.e., response and/or inquiry in either voice or data form. Thus, interactive capability can be included into any ITFS system.
- Since transmission is at 2500 MHz, requiring special receiving antennas and frequency converters before the signal can be received by standard TV sets, ITFS is essentially a private system, where the audience is specifically identified. In this respect, ITFS is similar to CCTV except that over-the-air broadcast techniques are used.
- The power output from ITFS transmitters is normally limited to a maximum of 10 watts. This restricts the practical area of coverage to about a 25-mile radius normally, and up to 40 or 50 miles with narrowly directed transmission.

- Being an "over-the-air" broadcast, ITFS is subject to the same problems of frequency crowding and interference as other broadcast systems, alleviated slightly by its restricted geographical coverage.

The key differences between ITFS and standard broadcast TV are analogous to "closed-loop" and "open-loop" systems, respectively. Because ITFS is a multiple-address, fixed point-to-point service, with the receiving audience closely controlled, feedback information on coverage, audience response, etc., can be regarded as almost a closed-loop process. Conversely, in ETV, the size, nature and response of the audience to educational material are tenuous and difficult to determine.

Thus, ITFS essentially offers a reserved frequency spectrum for limited, precisely defined educational purposes and audiences. As such, the institution operating the ITFS facility has close control over program content, time of presentation and audience selection. Effectively ITFS can be considered as performing the same function as CCTV, through point-to-point broadcast techniques and with different technical characteristics of coverage, cost and convenience.

9-2.2 Elements of an ITFS System

Figure 9-2 illustrates in block form the basic elements of an ITFS system. The program originating equipment is identical with that required for broadcast or CCTV studios, with the quantities and kind of equipment governed by the system needs and available funds.

The video and audio information, from whatever source, are connected into the modulation circuitry of a low-power (10 watt maximum) transmitter whose carrier frequency can cover the 2500-2690 MHz range. A maximum of 4 channels (each 6 MHz wide) are assigned to any single ITFS facility, so that the transmitter need only have 4 switchable channel settings, and broadcasts on

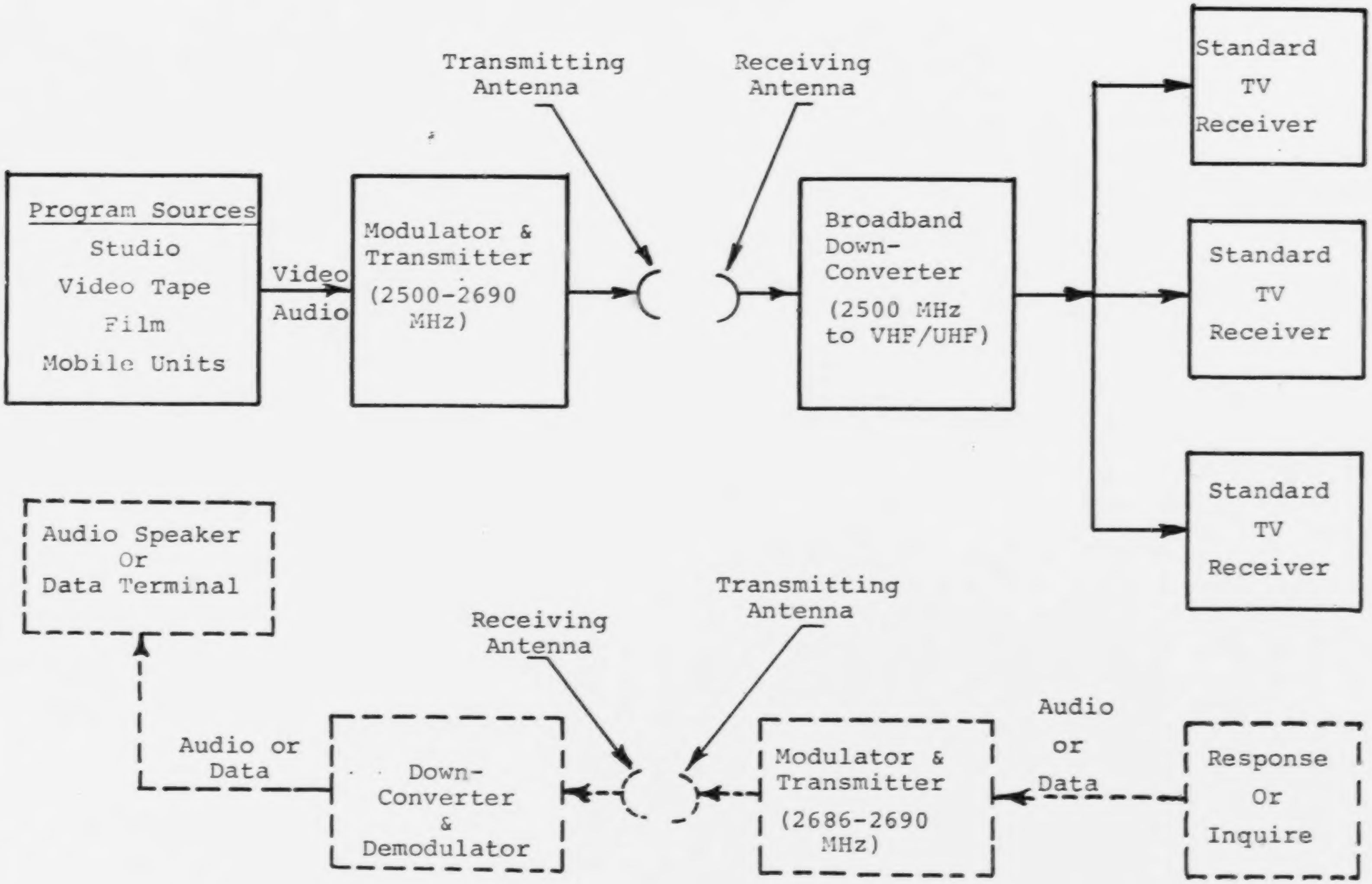

Program Sources
Studio
Video Tape
Film
Mobile Units
Video
Audio
Modulator & Transmitter (2500-2690 MHz)
Transmitting Antenna
Receiving Antenna
Broadband Down-Converter (2500 MHz to VHF/UHF)
Standard TV Receiver
Standard TV Receiver
Standard TV Receiver
Audio Speaker Or Data Terminal
Audio or Data
Down-Converter & Demodulator
Receiving Antenna
Transmitting Antenna
Modulator & Transmitter (2686-2690 MHz)
Audio or Data
Response Or Inquire

Figure 9-2
Elements of an ITFS System

a single channel at any particular time. Duplicate transmitter facilities are used if simultaneous broadcast over more than one channel is desired, and the transmitter outputs may be multiplexed to a single transmitting antenna.

The transmitting antenna may be either omnidirectional or highly directive, depending on the desired geographic coverage. The highly directional output will reach receivers at a greater distance, but only along the narrowly beamed path.

A receiving antenna is required at each receiving location, mechanically "aimed" at the transmitter for maximum signal strength. At or near the antenna location, a frequency "down-converter" translates the 2500 MHz microwave carrier frequencies to a standard VHF or UHF frequency so that a standard TV set can be used as a receiver. Usually, the VHF frequency selected is that of a channel unused in that particular geographical area so that interference from commercial or ETV broadcasts is minimized.

If the receiving location is a school or industrial plant, the signal is distributed from the converter to as many classrooms or individual receivers as desired, via coaxial cable.

Fig. 9-2 also illustrates a "response" or "inquiry" reverse transmission system by which the student can communicate back to the original program source location. As noted, the 2686-2690 MHz portion of the assigned ITFS spectrum has been designated for this purpose.

If the inquiry is a voice signal, a microphone input is used. If in the form of alphanumeric data, a teleprinter might be utilized. In either event, the audio or data signal is connected into a modulator-transmitter operating in the particular assigned section of the 2686-2690 MHz band, and broadcast in the reverse direction to a receiver and converter at the program origination location. The demodulated voice or data signal is then made available as desired.

9-2.3 ITFS Applications

ITFS has been authorized for over eight years as a specialized educational broadcast service. A recent survey (Educational Product Report No. 31, "ITFS", 1971) lists a total of 65 operating ITFS systems located in 21 states. Of the 65, 21 are located in only two states, New York and California

Thus, to date the utilization of ITFS has been rather meager, and there is some agitation to transfer a portion of the assigned ITFS spectrum to other applications. The decision of the 1971 World Radio Conference to reserve the 2500-2690 MHz band for educational communications, both satellite and terrestrial, will mitigate against such changes. For satellite communications, 2500 MHz is an "efficient" frequency in terms of the RF power that can be generated and radiated to ground antennas.

In this respect, it has been proposed that the NASA Applications Technology Satellite, Model G (ATS-G), scheduled for launch in 1974, carry a 2500 MHz transmitter specifically for broadcasting educational TV programs to a large number of ITFS receiving stations (ATS-F is already scheduled to broadcast ITV to India, using the lower 800 MHz UHF frequency). This capability could effectively "network" many ITFS systems, allowing them all to broadcast the same program simultaneously. If 4 channels were utilized, a choice of 4 programs would be available (more than from the 3-network commercial system at present).

Though this mass distribution capability will no doubt expand 2500 MHz educational broadcasting, its usage runs somewhat contrary to the present configurations of ITFS systems, which are essentially point-to-point, controlled audience systems. Thus, "networking", while permitting program interchange, might diffuse the intended audience.

The future of ITFS depends more on application than on technology. The technology and hardware of 2500 MHz broadcasting are essentially stable at this time, and no revolutionary breakthroughs are expected.

As with any wireless transmission, ITFS is subject to RF interference. If a substantial number of users in the same geographical area apply for an ITFS license, the question of interference becomes complex and critical. In the Los Angeles basin, for example, a computer program was developed by an engineering consultant firm, Hammet and Edison, to determine optimum locations and possible interference among a number of ITFS applicants.

Rather than a proliferation of separate ITFS systems, each serving its own parochial function, there has been some impetus toward "community-oriented" ITFS. In Cleveland, when a multiplicity of applications reached the FCC, the Commission asked the applicants, in effect, to settle the issue themselves. The result was an "umbrella" agency in which all interested parties participated on a community-wide basis. This agency, the Educational Television Association of Metropolitan Cleveland, was granted an ITFS license for the use of 16 channels (the FCC waived, in this case, the 4-channel limit), which will be used for all participants (including the Diocese of Cleveland, the Cleveland Commission on Higher Education, the Board of Education, the Education Research Council, the Cleveland Academy of Medicine, etc.).

The further formation of such consortia may stimulate the growth of ITFS, since two functions are achieved, a wider base for amortizing costs and the reduction of competition for a limited number of frequencies. Barriers to this form of growth are more political and organizational than technological.

9-3 Communications Satellites

9-3.1 Description and Background

A communications satellite is basically an information relay, linking terrestrial transmitting and receiving stations. Signals are transmitted up to the satellite (uplink), where they are usually translated in frequency to avoid interference, and retransmitted down to the earth. Retransmission (downlink), may be directional, aimed at selected receiver locations, or designed to provide broad coverage over a large portion of the earth's surface.

As a communications link, the satellite competes against wired connections (land-line or submarine cable), terrestrial wireless, or hybrid combination of both. In this competition, the satellite's advantages are:

- o Ability to reach remote areas where terrestrial links would be impractical or too costly. Considering the U.S. only, Alaska would be a prime example.
- o Ability to distribute one signal to a multiplicity of receiving stations, with cost being independent of transmission distance. Thus, there is an economic advantage on the long-distance routes.
- o Ability to transmit without signal loss due to line-of-sight barriers (e.g., mountains, earth curvature).

The offsetting disadvantages of the satellite include:

- o Limited useful life and lower reliability than terrestrial links.
- o As yet, relatively low power radiating capability, necessitating large and expensive ground stations.
- o Increased possibility of electromagnetic interference, both between satellite and terrestrial sources and among satellites themselves as orbital space becomes more crowded.

Considering that only some ten years covers the full span of communications satellite technology, and the achievements in that short time, it is obvious that rapid advance in development and utilization will continue for the foreseeable future.

Excluding some military applications, the major advances in technology have been contributed by NASA and ComSat. ECHO, a passive inflated balloon with metallized surfaces, was orbited by NASA in 1961 and served simply as a reflector off which signals could be "bounced". This was followed in the early 1960's by RELAY, a relatively primitive signal repeater and by the SYNCOM series. SYNCOM was the first satellite to demonstrate the feasibility of geostationary, or "synchronous", orbit technology, now used extensively. With this technique, the orbit is selected sufficiently high that the satellite revolves around the earth's axis in exactly 24 hours. If launched in a synchronous orbit over the Equator, the satellite appears to be stationary above one point on earth. It can therefore continue to receive from and transmit to the same ground stations without interruption, or change in signal strength.

In 1962 Congress passed legislation bringing the Communications Satellite Corporation (ComSat) into existence as a government-regulated, publicly owned corporation. ComSat's charter to develop and operate communications satellites was aimed primarily at international communications, and there was no monopoly over, or prohibition from, the area of U.S. domestic communications.

In 1964 the International Telecommunications Satellite Consortium (INTELSAT) was formed as a multinational joint venture. Interim agreements were concluded to permit development of satellites whose facilities could be used by all INTELSAT members. Membership is open to any nation which is a member of the International Telecommunication Union (ITU). INTELSAT membership has grown from an initial 14 to 77 nations at present.

Under the agreements, INTELSAT owns the operational satellites, while the ground stations are owned and operated in accordance with the domestic law of the country in which they are located. INTELSAT sets certain technical standards before ground stations are permitted access to the satellites.

Four series of satellites have been launched, INTELSAT I, II, III, IV:

(1) INTELSAT I (Early Bird)
  - Became operational June 1965.
  - Positioned over the Atlantic Ocean to provide communication between Europe and northeast U.S.
  - Capacity: 240-300 telephone circuits (or equivalent bandwidth).
  - Retired from service August 1969.

(2) INTELSAT II
  - Four satellites were launched, two became operational April and November 1967.
  - Positioned over Atlantic and Pacific respectively.
  - Capacity: 240 telephone circuits but with "multiple-access" feature (indefinite number of earth stations can access simultaneously).
  - Still operating.

(3) INTELSAT III
  - Eight satellites launched between September 1968 and July 1970, five became operational.
  - Capacity: 1200 telephone circuits plus one video channel
  - Four still operating, two over Atlantic, one over Pacific, one over Indian Ocean.

(4) INTELSAT IV
  - First and second of this series launched.
  - Became operational 1971-72
  - Atlantic and Pacific region service
  - Capacity: 300 to 9000 telephone circuits or 12 TV channels.

All of these satellites are of the "point-to-point" type, i.e., any single message travels from the originating earth station to only one receiving station. Because of the present limitations on satellite power, the earth stations require large steerable antennas with diameters in the order of 90-100 feet, plus sensitive receiving equipment, sometimes cryogenically cooled. Present cost for a typical station is 3 to 4 million dollars. This factor makes such a link cost-competitive only over very long land distances (although it is already competitive with underocean cables).

Since INTELSAT is concerned only with international communications, many large users of communications facilities have considered the advantages of domestic satellites which would provide links only within the confines of the U.S.

In March 1970, the FCC invited applications for the establishment of domestic communication satellite facilities by "non-government" entities. In response, many applications were submitted for both general-purpose satellites (ComSat, MCI Lockheed) and for "dedicated" single-purpose satellites, such as CATV networking (Hughes-TelePrompter) or commercial TV (the broadcast networks). No application approvals have yet been granted, which means at least 3-5 years will elapse before these satellites could become operational.

9-3.2 Application to Education

At present, satellites depend upon large sensitive ground station antennas and expensive facilities, because they cannot transmit much power. It is likely that when the first U.S. domestic satellites are operational, size and weight constraints on the orbiting payload will continue to limit transmitting power, although it may be an order of magnitude higher. This means that fairly large, commonly shared, ground stations will still be required although the cost may be in thousands of dollars rather than millions.

With centralized ground stations, distribution to individual users is made through common-carrier landline or wireless links. At high traffic density or over long distances or over impassable terrain the satellite link becomes cost competitive with other options. Otherwise, it is likely that alternate terrestrial links will be cheaper for some time to come.

In terms of potential impact on education, a series of projected NASA experiments offer a good indication of future applications.

The NASA Applications Technology Satellite (ATS) series of research satellites (of which ATS-I, launched in 1966, and ATS-III in 1967 are still operational) provide "test beds" for improving communications satellite technology. Present plans are for two new satellites ATS-F and -G, to be launched in 1973 and 1974, respectively. These will increase the effective radiated power considerably over the levels of previous models.

The increased antenna directivity and power output will permit reception by far smaller earth stations than previously, thus having more relevance to community-oriented applications. Among the wide variety of experiments scheduled for ATS-F, the so-called "India Instructional TV Experiment" is of special interest.

The background of this experiment is India's interest in providing Instructional TV coverage to as large a segment of its population as possible, including not only the metropolitan areas, but most particularly the primitive outlying villages in greater need of ITV. The Indian government conducted cost studies of three approaches to obtaining ITV coverage:

- Rebroadcast stations with microwave interconnection
- Rebroadcast stations with satellite interconnection
- Satellite broadcasting exclusively

The studies indicated satellite broadcasting exclusively to be the lowest-cost approach. The Indian government then concluded an agreement with NASA to conduct the ITV experiment, using ATS-F. After the first six to nine months of operation of ATS-F, the satellite will be repositioned to about 20° east longitude, permitting coverage of most of India, yet minimizing the possibility of interfering with conventional VHF/UHV service in Europe.

During the experiment, the satellite will provide one UHF (800 MHz) TV channel for four to six hours per day. The program material will be transmitted to the satellite from a station at Ahmadabad, and beamed from the satellite down to a complex of large, metropolitan-area and smaller, community-area receivers. The large receivers will be connected to rebroadcast stations which serve TV sets in the surrounding metropolis. The community receivers (using antennas about ten feet in diameter) will be distributed among some 2000 villages, each of which may have only one or a few TV receivers.

India will develop, install, operate, and maintain all necessary ground facilities and be responsible for the ITV program material. In return for the use of NASA's satellite, data from the experiment will be made available to the U.S. without cost. This is particularly useful, as a 6 MHz-wide frequency channel necessary for ITV is simply not available from any other satellite on a no-charge, long-term basis.

One item of note in connection with this experiment is that NASA, in search of low-cost ground station components, has a developmental model of a ten-foot parabolic antenna estimated to cost $75 in production. This consists of a parabolic framework of brass tubing, resembling the spoke structure of an extended umbrella, covered with chicken wire.

So far as U.S. education is concerned, the first impact from communications satellite technology will not come before establishment of an operational domestic satellite, since INTELSAT, because of its multinational structure and objectives, has no responsibility for educational applications.

The NASA-India ITV experiment in 1973 or 1974 will be of great interest, but only as a source of information for guidance in the future. The earliest time that a domestic satellite might be operational is about 1975, since FCC action in this area is still forthcoming. If the only satellites licensed by the FCC are of the general-purpose type, the effect on education will probably not be significant unless some educational subsidy such as free or low-cost educational channels is included. Even with such subsidy, the cost of access to the centralized ground stations migh be sufficient to discourage taking full advantage of the opportunity.

Thus, the major impact on educational applications can be expected from either of two developments:

- A satellite which can broadcast to community-type earth stations.
- A satellite which can broadcast directly to the home and/or school. The high power level necessary, however, to provide good signals to cheap home antennas does not appear feasible for 5-10 years.

Of special interest in the "community" category is the "satellite-for-CATV" proposed by Hughes-TelePrompter. The purpose of this type is to receive TV program material from one or a limited number of origination stations and distribute this material simultaneously to a large number of CATV systems all over the U.S. (Four different transmitters and antennas could cover all U.S. time zones). It can be termed a "distribution" satellite (rather than the point-to-point type heretofore in general use), and in concept is similar to the Indian ITV experiment. In the U.S., however, thousands of CATV systems are already established, with head-end facilities and cable distribution networks. The ground facilities are therefore already substantially in place and have been or are being amortized by subscriber payments.

Therefore, to accomplish the "networking" of CATV systems and allow program sharing, the communications satellite appears to offer by far the best solution. The key consideration will be achieving sufficient power and directivity to reduce the cost of the receiving installation at each CATV head-end to a reasonable figure (perhaps $10-50,000).

In any event, an operating satellite for CATV can offer new vistas for education. Local school districts would not be burdened with individual program preparation costs as they could use "networked" ETV or ITV programs, at least for many requirements if not all. Further, the availability of CATV channel space for education, and the connections to schools, eliminate the cost of distribution either for on-campus or off-campus instruction.

In terms of distribution to the audience, the number of communities having CATV is still too small to be considered as providing adequate coverage to the U.S., or indeed to U.S. schools.

A more comprehensive example (which has been proposed informally) would be a satellite broadcasting to one ground station in each U.S. school district, about 20,000 at present. Within each district, the signal would be distributed to each school and perhaps also to local broadcast stations or CATV systems so that home audiences could be reached. This concept, if implemented, would provide almost complete coverage to both on-campus and off-campus audiences.

The most likely occurrence is a hybrid system. If, for example, the CATV/satellite link is authorized and becomes operational, it is conceivable that those school districts which do not have CATV systems in their area may find it possible either to establish their own ground stations or tie in, via ITFS microwave or landline, to the closest CATV head-end. Since public policy appears to have confirmed the requirement for free educational channels on CATV distribution cables, it is likely that one or more satellite channels will also be so allocated. Thus, the educational districts may be able to "piggy-back" on the satellite-for-CATV concept, whose primary economic justification would be networking of CATV systems to receive commercial TV broadcasts. Such an educational piggy-back could make at least a few TV channels available for educational purposes on a nationwide basis, permitting almost 100% coverage to schools for a relatively modest capital cost. Further, under the given assumptions, this coverage could conceivably take place by 1975-77. Coverage to the full at-home population would still have to await a direct broadcast satellite.

Summing up the current state of satellite communications technology, no substantial educational benefits (or even applications) have yet ensued. The future, however, is particularly bright, especially when "community" reception can be achieved at reasonable cost.

9-4 Electro-Optical Transmission

The pressure toward utilization of the higher portions of the frequency spectrum, and the potential for using these higher-frequency carriers to transmit orders-of-magnitude increases in information, has led to exploration of electro-optical communications.

Although no near-term educational applications are envisioned, the long-range potential of this field is sufficiently great to warrant a brief examination.

Electro-optical communications uses the area of the electromagnetic spectrum around and including the visible light region as the carrier for the information to be transmitted.

Two types of optical transmission are possible, "incoherent" and "coherent". Coherent light, obtainable only from lasers, is essentially a very precise, stable, single-frequency radiation.

It can be focused sharply into very narrow beams, and because of its"pureness" and stability of frequency, can theoretically be modulated and combined with great accuracy in much the same way as radio frequencies.

Incoherent light is more diffuse and contains multiple frequencies within a restricted band. Its information-carrying potential is much less than coherent light.

The potential advantages of optical transmission include:

- The much higher carrier frequencies of the optical band (about 1,000,000 times higher than the VHF/UHF band) permit greater bandwidth modulation, and therefore the capability to transmit much more information. Lack of adequate modulators at present, however, prevents full exploitation of this feature.
- Complete electrical isolation between transmitter and receiver is achievable, if desired.
- Higher transmission security, and less stray radiation, because of the extremely narrow signal beams.
- No generation of, or susceptibility to, electromagnetic interference.
- Little requirement for "impedance matching".
- Generally smaller transmission/reception equipment than for radio or microwave frequencies.

Counterbalancing these potential advantages are some severe limitations, at least at present:

- Optical transmission is limited to "line-of-sight" even more stringently than microwaves. A translucent or opaque object intersecting the light beam will interrupt transmission.
- Atmospheric characteristics (e.g. rain, fog, smoke, turbulence, etc.) strongly affect the quality of transmission.
- Greater susceptibility to equipment vibration.

- Current low efficiency and power capacity of light emitters and poor sensitivity of detectors.

These limitations will, for some time to come, constrain optical communications links to specialized, short-range applications. Nevertheless, the potential advantages, particularly greater information handling capacity, remain attractive enough to spur further development.

CHAPTER 9 - BIBLIOGRAPHY

1. "Instructional Television Fixed Service", Educational Product Report No. 31, Education Products Information Exchange, New York, Jan. 1971.

2. "ITFS, A New Concept for ITV Distribution", Booklet No. 4, Maryland Center for Public Broadcasting, 1969

3. "ITFS - Instructional Television Fixed Service (2500 megahertz): What it is - How to Plan", Division of Educational Technology, National Education Association, Wash., D.C., 1967

4. Kessler,W. J., "ITFS - An Assessment of Technical Requirements", Division of Educational Technology, National Education Association, Wash., D.C., 1967.

5. "Satellite Communications for U.S. Schools" Stanford Research Institute, prepared for MCI Lockheed Satellite Corp., Feb. 1971.

6. Sielman, P.F., "Satellite Educational Television - An Effective Form of Foreign Aid", Presented at the AIAA Conference, Oct. 1967.

7. Sielman, P.F., "Satellite Educational Television for Underdeveloped Countries", Presented at the 19th Congress of the International Aeronautical Federation, Oct. 1968.

IV. INTEGRATED EDUCATIONAL SYSTEMS

Chapter 10 Audio Systems
Chapter 11 Audio/Visual Systems
Chapter 12 Computer - Based Systems

CHAPTER 10 - AUDIO SYSTEMS

Because of the extensive development of audio communications networks for commercial and public use, there are many examples of educational audio systems, some of which have been in operation for years. "Language laboratories", for example, featuring the learning of foreign languages by many students simultaneously, were developed in the 1930's and utilized extensively during World War II, when the need for rapid training of large numbers of students became urgent. The use of radio for education, as another case, goes back over 50 years.

To illustrate the variety of systems possible, examples have been selected which feature:

(1) "Individualized instruction" systems of the "learning laboratory" type, ranging up to extensive Dial-Access Retrieval facilities
(2) Educational Telephone (ETN) systems in which the commercial telephone network is a key communications element
(3) Educational Radio (ER) systems which broadcast program material over the air, either to a general or specialized audience.

While by no means exhausting either the kinds of systems which are possible, or, indeed, those already tried, these categories do utilize a broad range of components and techniques, sufficient to indicate both what has been done and what might be done in the future.

10-1 "Individualized Instruction" Systems

It has long been recognized by educators that the capability for "individualized instruction", which would permit each student to learn at his own pace, is a desirable objective. The size of classes in most schools effectively prevents the instructor from achieving, or even approaching, this objective, and the assistance of technology has been called upon to provide the means.

Individualized audio instruction has been common practice in schools since the advent of the magnetic tape recorder. Usually, however, there was a "one-to-one" relationship, i.e., one recorder/player per student. This is expensive, both in the cost of equipment and the utilization factor.

A more economical approach is the centralized instructional facility, or "learning laboratory", where equipment, programs and support facilities can be clustered for efficient use, and directed to students upon request.

10-1.1 The Learning Laboratory

As illustrated in Fig. 10-1, a typical learning laboratory includes a centralized repository of recorded audio programs (usually on tape), and means for switching the played-back programs into any of a number of student learning booths called "carrels".

The control equipment may include an instructor's console which enables the teacher to monitor, record, or communicate with any student and direct a particular program to him.

Carrels are equipped with headphones and a means for requesting or initiating playback of a program. In the simplest form, where the recorded program is fixed, this may be only an "On-Off" switch, while in the more complex systems, such as the Dial-Access systems described later, a keyboard or dial terminal is furnished to permit requesting a specific program by assigned code number.

The carrels also may be capable of either a "passive" or an "active" mode. In the former, the student can only listen to the prerecorded program, while on the latter he also can speak into a microphone, have his voice recorded and compare

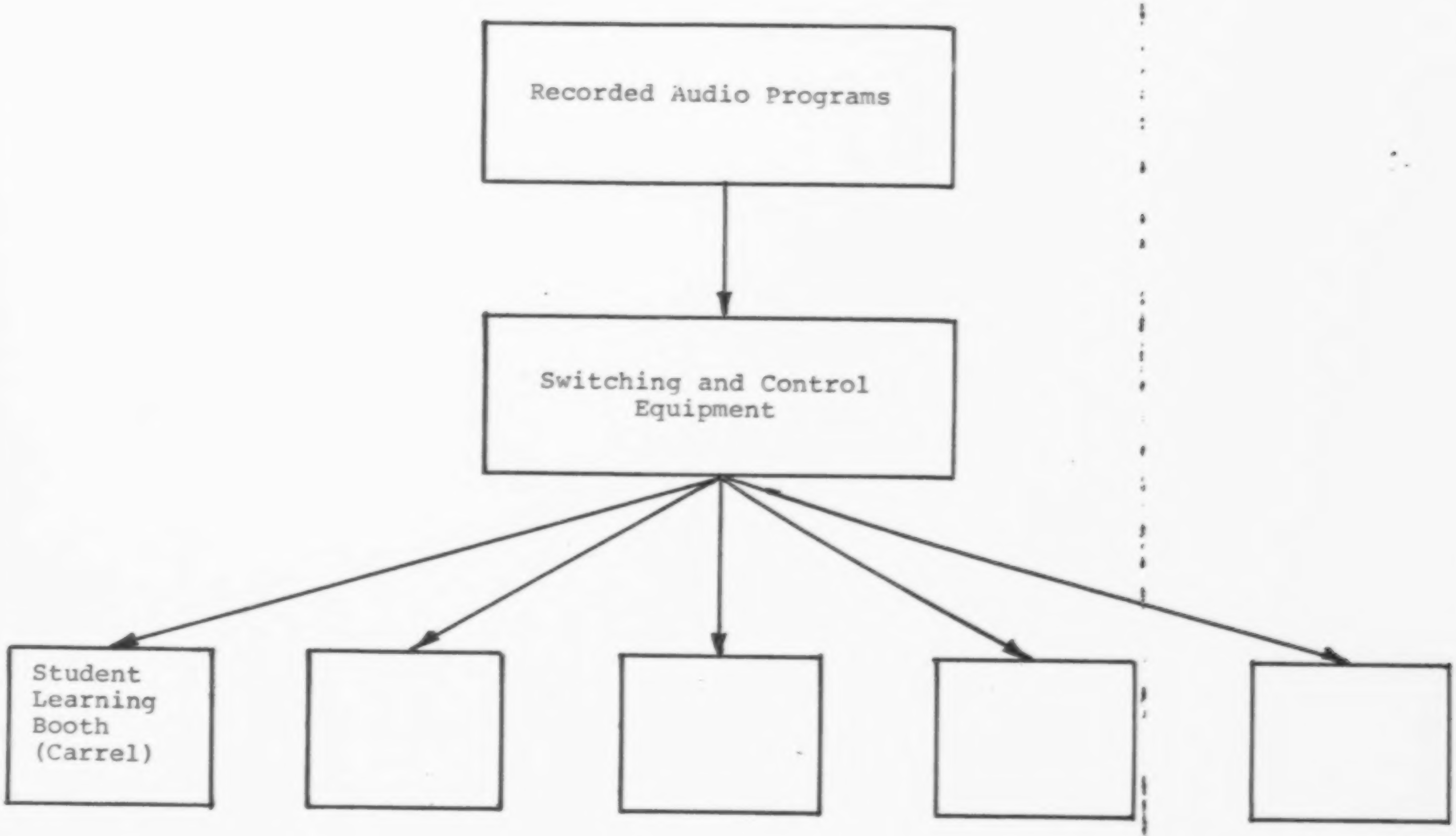

Recorded Audio Programs
Switching and Control Equipment
Student Learning Booth (Carrel)

Figure 10-1

Learning Laboratory

his response with the original. In learning languages, for example, this feature permits him to evaluate his accent and inflections, and is very valuable.

So long as the number of recorded audio programs and the number of students both remain low, the learning laboratory can be a relatively simple system. With a few programs, for example, it may be less expensive to provide a separate tape recorder/player for each program than to incorporate the switching facilities necessary to share one recorder. Similarly, with a limited number of students it may be feasible to schedule each program at a specific time, rather than upon student request.

As the quantity of programs and the number of users increase, individual access becomes much more complex. As a result, the learning laboratory has evolved into the automated Dial-Access information retrieval system. The concept remains the same, i.e., providing individualized instruction upon request, but the storage, switching and control equipment involve advanced telecommunications technology to a much greater degree.

10-1.2 Dial-Access Audio Information Retrieval

Dial-Access audio information retrieval systems have been in use in the U.S. for some ten years, with about 300 installations at all educational levels from elementary schools through universities.

The primary application to date has been as foreign language laboratories, providing access to audio information only. The more recent and elaborate installations accommodate both audio and video program material (examples of A/V Dial-Access are given in Chapter 11). In the A/V form, the system makes available by electronic transmission a wide variety of stored A/V educational materials for independent study or classroom instruction. It also has other capabilities, ranging from reception of community radio and TV stations to providing a link to a problem-solving computer.

The basic components and interconnection of a Dial-Access audio system are the same as in Figure 10-1, except that each block now contains more complex and flexible equipment.

The carrel retains its earphones and volume control for listening to the program, but now incorporates a request/selection device. This may be the dial portion of a telephone (which gave rise to the term "Dial-Access"), a more recent Touch-Tone telephone keyboard, or an equivalent keyboard of special design. The dial and Touch-Tone mechanisms have been used because their volume production in telephone use has resulted in a relatively low cost, and also because of their compatibility with other telephone components that may be used in the system.

In any event, the request/selection unit permits entry of the code number assigned to the desired program (an index is made available to all users). A 3-digit dialed number can, for example, select any of 999 programs.

The switching and control circuitry must then select the appropriate program, start it playing back and connect it to the carrel which inititiated the request. Since, for a system of 20 carrels and 50 programs, 1,000 combinations are possible, just keeping track of and controlling the interconnections is no small task. Some Dial-Access systems use small general-purpose computers for this function, while others employ special-purpose controllers.

Until the last few years, one drawback of Dial-Access audio systems was that if a program was in process of being played back by a student, another student requesting the same program either had to wait until playback was completed (which could be 15-30 minutes) or start listening in the middle. This was due to the fact that the program was stored on only one tape (or, at best, two or three) and the same tape was played back.

The introduction of high-speed dubbing has alleviated this problem. In more recent systems termed "Random Access", the program is stored on a "master" tape. When a student requests that program, it is reproduced (dubbed) at high speed onto a second tape which is the one played back to the carrel. The dubbing speed is high enough so that a waiting time of less than one minute is achieved under any circumstances. Thus, within one minute, the requested program starts playing back from the beginning, regardless of whether another student is already using it. Each request for that program results in a newly dubbed tape available to the requestor. Dubbing tapes are later erased and reused.

Another recent inovation, the cassette, permits still greater flexibility in using the Dial-Access system. By providing a cassette duplicator in the system, the student may purchase a blank cassette, insert it into the duplicator (possibly with a coin-operated device), and request that a specific program be dubbed onto the blank cassette. Once done, he takes the cassette back to his own player and listens to it at his convenience.

Figure 10-2 illustrates such a random access cassette system, produced by Ampex. The upper portion of the diagram shows the cassette duplicator unit. Program tapes are stored, in incremental modules of 32, so that the configuration illustrated can contain up to 96 programs. The student simply inserts a blank cassette into a slot in the duplicator, selects the program he wants, and presses a start button. Within a few seconds the duplication is complete.

Cassette duplicators may be placed in key locations on or off campus. A unit containing physics and chemistry programs, may, for example, be located in the school's science building.

The centralized system, shown at the bottom of Fig 10-2, can provide playback either to carrels or to remote locations. In the former case the audio program is sent to the carrel earphones, while in the latter the duplicate cassettes themselves

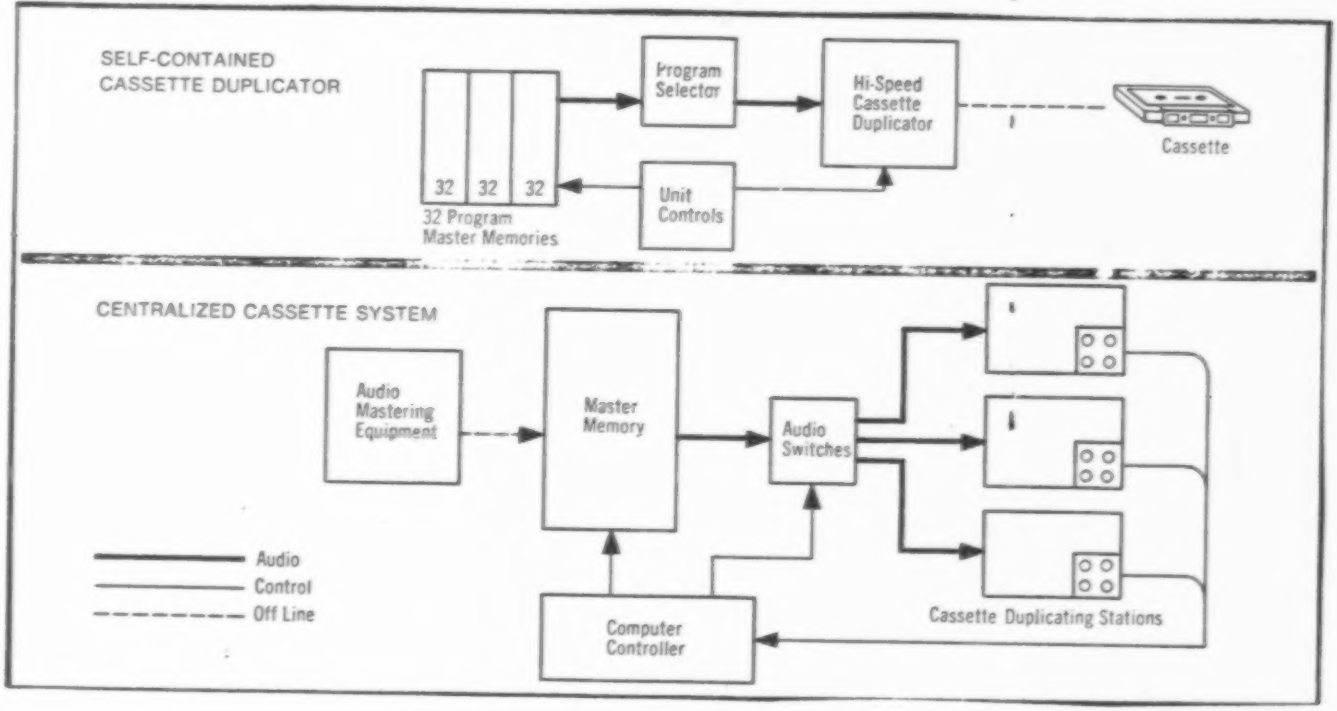

SELF-CONTAINED
CASSETTE DUPLICATOR
32
32
32
32 Program
Master Memories
Program
Selector
Unit
Controls
Hi-Speed
Cassette
Duplicator
Cassette
CENTRALIZED CASSETTE SYSTEM
Audio
Mastering
Equipment
Master
Memory
Audio
Switches
Computer
Controller
Cassette Duplicating Stations
Audio
Control
Off Line

Figure 10-2

Random Access Cassette System

are made available physically for playback on the user's equipment.

Table 10-1 provides an order of magnitude estimate of Dial-Access system equipment costs only. To this must be added the software costs of program preparation.

10-1.2.1 Oak Park and River Forest High School System

As one of the first Dial-Access audio installations to offer the random access feature described above, the system at Oak Park and River Forest High School, in suburban Chicago, can serve as an illustrative example.

In 1966, functional specifications were drawn up by the school's faculty for the system described below. Bids were let, and the first phase of the system was constructed and became operational in 1968. Funding was supplied by a U. S. Office of Education federal grant of almost $1,500,000 (over a 3-year period), supplemented by more than $1,000,000 in local and private funds.

Figure 10-3 illustrates the original system which accommodated 25 student carrels (5 to a pentagonal cluster) for audio programs only, with a choice of up to 224 recorded selections.

The master programs are stored on seven bin-loop tape transports, each holding 32 programs. These tapes are normally recorded at 3 inches per second.

The key to random access is that dubbing is accomplished at a tape speed of 120 inches per second, whenever a playback is requested. Thus what would normally be a 15-minute program is reproduced in 1/40 the time, or about 23 seconds. Actually, with switching time, and assuming the worst case that another student has just previously requested the same program, the maximum delay is less than one minute, whether one user or many request the same program.

	COST PER STUDENT POSITION ($)			
Capability	Carrel	Switching, Control and Power	Program Source (Recorder/Player)	Total Cost per Student Position
Audio-listen only (30-40 carrels)	200	300	500	1,000
Audio-active and record (30-40 carrels	400	600	1,000	2,000
Audio-random access, active and record (30-40 carrels	600	2,000	1,400	4,000

Table 10-1

Typical Equipment Costs - Dial-Access Audio System

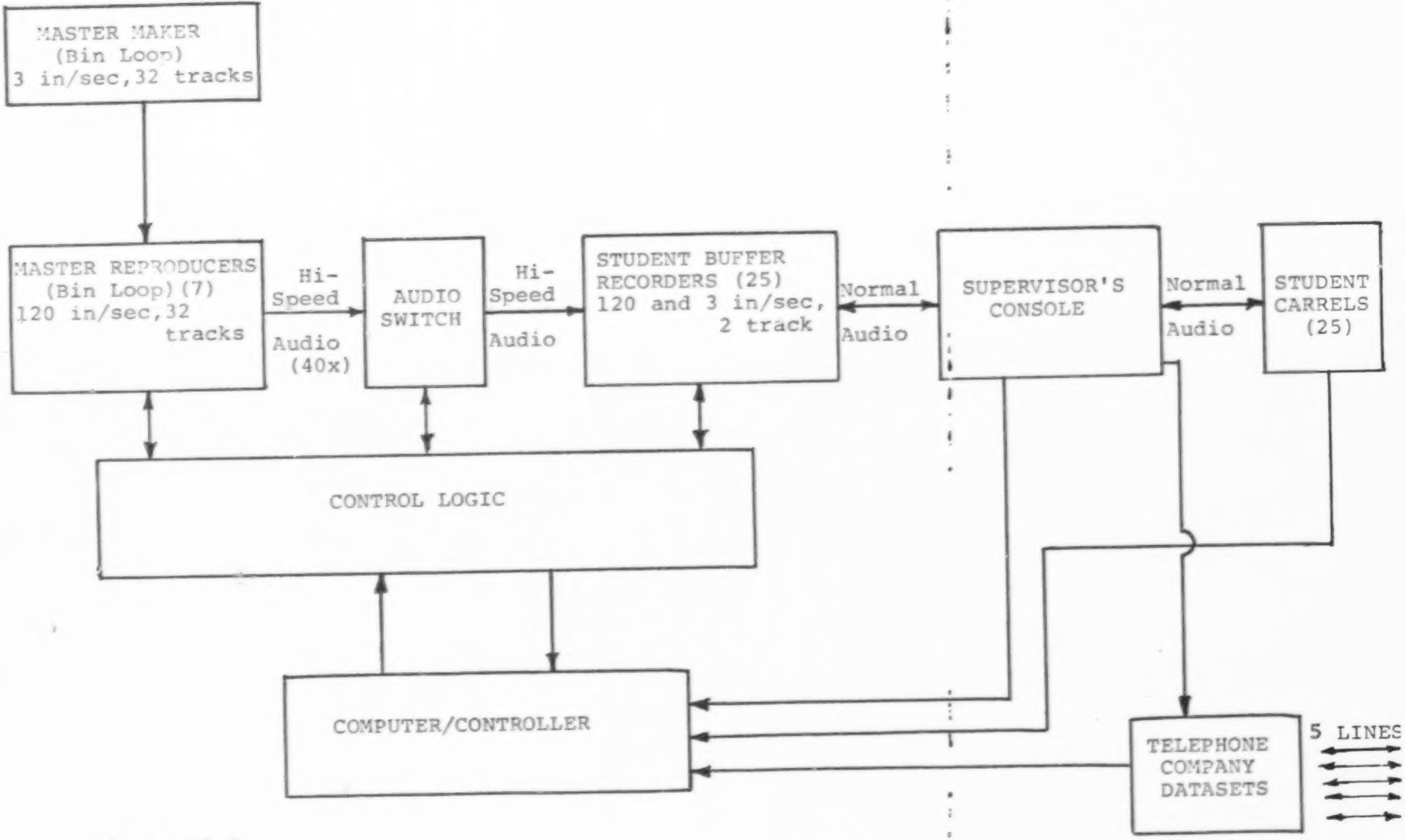

MASTER MAKER
(Bin Loop)
3 in/sec,32 tracks
MASTER REPRODUCERS
(Bin Loop)(7)
120 in/sec,32 tracks
Hi-Speed Audio (40x)
AUDIO SWITCH
Hi-Speed Audio
STUDENT BUFFER RECORDERS (25)
120 and 3 in/sec, 2 track
Normal Audio
SUPERVISOR'S CONSOLE
Normal Audio
STUDENT CARRELS (25)
CONTROL LOGIC
COMPUTER/CONTROLLER
TELEPHONE COMPANY DATASETS
5 LINES

Figure 10-3

Random Access Audio System at Oak Park and River Forest High School, Oak Park, Illinois

A computer/controller is used to control the selection and switching. It also has diagnostic capability which can test the 5,600 interconnection paths (224 program times 25 carrels) and report defects.

Five telephone data communications interfaces are provided to let other schools or shut-in students connect into the system.

The initial installation has since been expanded in a second phase to add 50 more carrels, for a total of 75, and also to carry video signals, although not on a random access basis. Phase 3 plans are for random access video, plus added receiving stations in classrooms and conference rooms.

Further details on the system components follow:

Carrels: Illuminated push buttons select program material and control program replay, student record and play, standby, and recue. Program recording is controlled only by the computer, but an indicator light in the carrel shows when the system is in this mode. Each student has earphones, a microphone (for language instruction or intercom), an instruction card, and directory of programs.

The student does not operate the equipment directly. All student requests go from the carrel keyboards to the computer which controls the entire system. The computer will reject an improper request or input. Because of this hands-off operation, students can't damage the system.

Keyboard control units can also be put in classrooms or auditoriums to connect into the system for group listening. Remote locations, including sick students at home or other schools, can connect into the system via five telephone interfaces. A TOUCH TONE telephone is all that is required at a remote location to draw on the library of recorded material.

Supervisor Console: Unattended operation of the system is possible, since it is entirely automatic. Audio for each student passes through the console and may be monitored. A complete intercom allows the supervisor to interrupt a program and talk with the student directly. An auxiliary keyboard/display unit on the console allows the supervisor to take over control of any student buffer, share control with the student, or completely disable a given position. The computer teletype, located on the console, also logs out each requested program number with the position that requested it. This can be expanded to log out the student number, if desired.

Computer: The computer is the nerve center of the entire system. Its program has a log of audio program numbers and student carrel numbers. The student can also insert his own number into the system in order to identify himself for logging and testing.

The computer selects the proper program track and connects it via an audio switcher to the carrel recorder to duplicate the lesson at high speed. The computer can also test the condition of the entire system each day using basic diagnostic programs. One of the test programs cycles every program source in all student positions and logs out on the teletype any defective paths. Any defective paths or units located with the diagnostic program are identified on the computer teletype for action.

Master Recorder: Master programs are recorded off-line on a master loop recorder which has 32 tracks on one-inch tape. This unit is manually controlled and records programs at 3 inch/sec from any regular input source such as a microphone, tape recorder, phonograph or radio. The tracks on the master recorder have separate erase and record heads so that each track is recorded independently of the other tracks and may be recorded, edited, or updated at any time.

Master Reproducers: These are 32-track one-inch bin-loop units. After a tape is made on the master recorder, the bin is placed on the master reproducer. Here it is played at 120 inch/sec to duplicate material for the carrel units.

Since these are loop recorders, the tape doesn't have to be rewound before the next program can be duplicated. Programs are available from the beginning immediately after a transfer is done. No time is lost in reversing the tape as in a conventional reel to reel recorder. Each master reproducer can transfer a single program to a single carrel recorder, a single program to all carrel recorders, or all 32 programs simultaneously to all carrel recorders.

Carrel Recorders: The student recorder/reproducers connected to each carrel are identical mechanically to the master reproducers, except they are half-inch dual track. They operate at 120 inch/sec when receiving a program from the master recorder, then play it back to the student for listening at 3 inch/sec. Transfer time is 30 seconds for a 15-minute program. The student can listen to the program as many times as he wants or record it on his own personal tape recorder. Track one contains program material for playback. Track two is for recording the student's own voice.

10-2 Telephone-Based Systems

The availability of the vast dial-up telephone network in the United States, supplemented by leased dedicated lines or user-installed and owned lines, makes it technologically feasible to utilize telephones for many educational applications, particularly under off-campus conditions. Where only audio information need be transmitted, the telephone network may serve as the complete distribution system, while in mixed-media applications, such as instructional television with student interaction, it may serve as an audio subsystem of the total system.

The cost, however, may be prohibitive in many cases. Even in the most favorable case where all lines are local and toll-free, the equivalent cost of $0.10 for a 3-minute or less call, totals $2.00 per hour for a single point-to-point application. Unless more than one user can time-share the line facilities, few educational institutions can bear these costs. Current commercial computer time-sharing systems, as an example, are burdened with high line costs which can be justified only above a substantial threshold of usage.

Where cost-effectiveness can be demonstrated, educational telephone can be extremely useful. The introduction of the Touch-Tone phone provides a truly low cost terminal which can be used to input numeric information to a central location where either CAI, data retrieval or computer time-sharing functions take place. If the response to the user is in aural form and does not require special printers or display facilities, then all of the capital investment costs are in the central equipment and essentially none at the users site.

Other than cost, another practical imitation to telephone system usage, at least in the dial-up network, is the high volume of traffic being handled, with some consequent degradation in service. For aural applications, this is not yet significant, but for data flow, many current users can attest to marginal adequacy at best, in terms of line conditions leading to excessive noise, outages, high error rates, etc.

Massive efforts are underway by the common carriers to improve and expand the voice-frequency communications network, particularly with respect to data traffic. In the latter case, applications are pending before the FCC to authorize the construction and operation of large-scale, new data communications system by non-common-carriers. It appears at this time that one or more of these proposed networks will be constructed, probably in the next five years.

Simultaneously, the establishment of domestic communications satellites will provide more relaying capacity, both point-to-point and, more importantly, on a distributed basis from one point to many reception points.

The effect of this expanded capability will be to permit educational applications in the future to use the voice/data network on a more cost-effective basis, although communications costs may yet remain the major barrier to wider implementation.

Meanwhile, many education applications utilizing telephone communications have taken place. Two examples are described below.

10-2.1 Educational Telephone Network (ETN)

The Educational Telephone Network (ETN), developed by the University of Wisconsin, links some 50 courthouses, 15 University of Wisconsin campuses and centers, and 56 hospitals throughout the state.

ETN is a private telephone network that takes the form of a huge party line. It is designed for maximum flexibility and practical approximation to across-the-table discussion.

All of the outlying points on the network have identical equipment, consisting of a speaker and telephone handset. By picking up the handset, a participant can talk to all listening points connected to the system.

ETN was originally developed to provide continuing education to M.D.'s throughout the state; the first post-graduate medical program was conducted via ETN in 1965. ETN has expanded since then to include programs on law, pharmacy, staff training and development, social work, library science, nursing, 4H, engineering and music. College credit courses, including home economics, library science, veterinarian science, physics, sociology and English have been provided.

A typical program varies from 1-2 hours, normally with a live or taped lecture followed by a question-and-answer period. To ask a question, a listener simply lifts his handset and speaks, and is heard over the entire network.

Visual materials are sent out to each listening station as desired, and used in conjunction with or to supplement the telephonic sessions.

Equipment is available to extend the ETN concept to include transmission of visual material in conjunction with the audio. "Blackboard-by-wire", "Tele-class" and "Remote Blackboard" are various designations for systems which can scan static or slowly moving visual objects, such as a blackboard, convert the image into electrical form, and send it over a second telephone line so that it can be received and reproduced at the same time the audio message is heard. These systems are described more fully in Chapter 11.

The key factor, however, remains the line costs. Estimates for equipment to provide 2-way audio-and-graphic communication between two classrooms range from $5,000 - $10,000. The annual cost of a phone line, used 8 hours per day, may easily exceed this, particularly where toll charges are involved. For an all-audio system, the discrepency is even more outstanding, since the terminal equipment cost becomes almost negligible.

10-2.2 Telephone-Based Dial-Access

Most campus-based Dial-Access retrieval systems can be expanded off-campus by using the telephone network to permit outside users to obtain access to the system. All that is needed is appropriate interface equipment to insure that the outside call is made to "look like" an internal request so far as the system is concerned. Two limitations will restrict unlimited expansion, communication costs, and the response capability of the system, i.e., how many calls will "saturate" it.

One system of interest, termed "Dial-a-Drill", is being studied on a pilot basis in New York City. This application is essentially a Computer-Assisted-Instruction project with the phone network acting only as a communications aid, but since it provides a voice response rather than data or graphics, it is appropriate for this section.

The "Dial-a-Drill" system can drill several thousand students, at home, in the fundamentals of arithmetic, using a time-shared computer programmed to drill the students orally at their own rate.

A student may call into a central location, or, conversely, an attendant at the central location calls a student, and after verifying that he is ready for his lesson, transfers him to the computer. If the student needs assistance at any time, the attendant can be summoned in on any line.

The computer, using a voice-response unit, poses questions in subtraction, addition, multiplication, division, fractions, etc., in varying degrees of difficulty depending upon student progress. The student responds (i.e. gives the answers) by pushing appropriate buttons on his home Touch-Tone telephone, used here as an input terminal. A cumulative record is maintained on each student's level of achievement.

Since the student does not directly dial his program, this system may be somewhat less than a pure Dial-Access type. If implemented past the pilot stage, however, further automation is to be expected.

10-3 Educational Radio

The use of radio for educational purposes is one of the oldest applications of communications. In 1919, over fifty years ago, station WHA, licensed to the University of Wisconsin, began experimental operation. WHA is still broadcasting and is the originating point for a Wisconsin state network of 11 educational radio stations.

In 1941, FM broadcasting was authorized and the number of educational stations on the air grew rapidly following World War II. At the beginning of 1971, more than 475 educational radio stations were licensed by the FCC. About 40% of this total went on the air between 1966-70, indicating the extent of recent growth.

In addition to broadcast systems, about 500 closed-circuit carrier-current or wired-wireless campus systems are operated by educational institutions. These require no FCC license.

Of the 475 currently operating stations, only about 25 operate in the Amlitude-Modulation (AM) band, 550-1600 KHz No AM frequencies are reserved for educational use and the crowding of this portion of the spectrum inhibits the possibility of new stations.

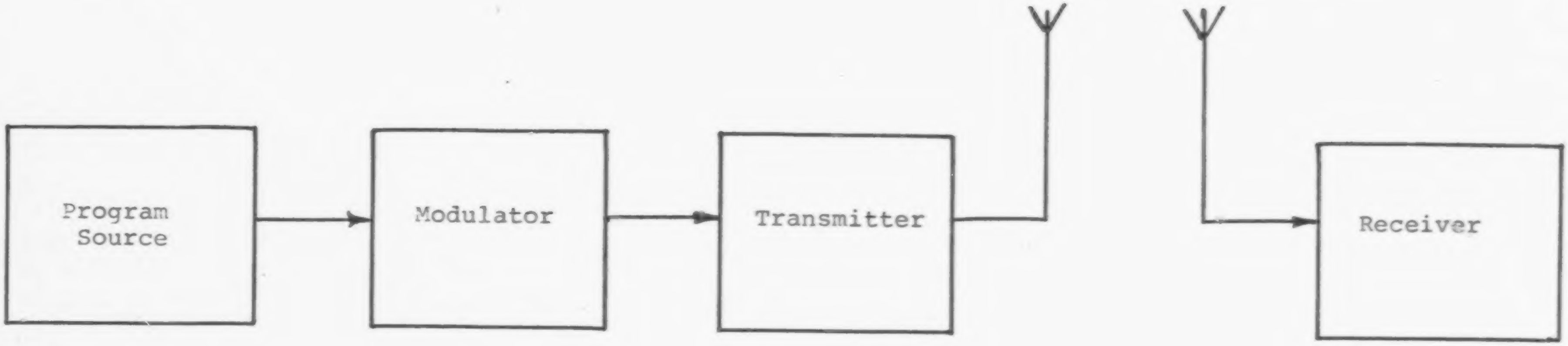

Program Source
Modulator
Transmitter
Receiver

Figure 10-4

Radio Broadcast System

In the FM range, however, the FCC has reserved the portion between 88 and 92 MHz for noncommercial educational stations, and consequently this is where most educational stations presently operate. Almost all the educational stations licensed in the last 5 years have been FM.

About 72% of the FM educational stations are licensed to colleges and universities, about 17% to local boards of education and schools, 6% to churches and religious organizations, and the remainder to community corporations, libraries and other organizations.

About 45% of all educational FM stations are low-power (10 watts) units, broadcasting over a limited 2-5 mile radius, and requiring a total capital investment of only a few thousand dollars. A higher-power FM transmitter, perhaps up to 100 watts, might serve a radius of 10-20 miles, at an equipment cost of perhaps $25,000.

Because of the limited availability of frequencies in the broadcast spectrum, no startling growth is expected in terms of number of new educational radio stations, Restriction to low power eases the problem of radiation interference to some extent, but the burden is still on new applicants to demonstrate non-interference operation, which can be difficult and expensive.

An expansion in FM multiplexing (described in Chapter 3), however, may be expected since this requires no new frequency allocation and, indeed, permits the FM station to secure income from sources other than broadcast advertisers or audience contribution. A correspondence course, for example, can be multiplexed only to students registering for the course (the special receiver is furnished to them only for the course duration), and the registration fees are used to defer costs and hopefully produce some income.

Radio can also serve as an element in more complex educational systems, such as a dial-access retreival of audio program material, or the interactive "talkback" portion of an ETV/ITV system.

10-3.1 Radio Networking

In 1950, the first national network of U.S. educational radio stations was established. Originally the Tape Network of the National Association of Educational Broadcasters (NAEB), and later called the National Educational Radio (NER) division of NAEB, it distributed recorded programs to affiliated stations.

In September 1965, the first interconnection (networking) of some 70 NER stations took place; since then repeated many times for special programs.

With the formation of the Corporation for Public Broadcasting by Congress in 1967, CPB took on responsibilities for stimulating the growth of educational radio as well as TV. In March 1970, CPB formed National Public Radio (NPR) as a national noncommercial radio service. NPR functions include live interconnection and other program distribution systems (networking), coverage of public events, development of programs and establishment of foreign program exchange.

CPB provides some funds to those radio stations which meet minimum criteria with respect to broadcast hours, transmission power, staffing and quality of programming. A total of 96 stations were deemed eligible for CPB grants by the end of 1970.

NPR's network is eventually to interconnect some 100 public/educational radio stations, and is expected to produce extensive public affairs programming.

With the advent of domestic communications satellites, both radio and TV station networking will be enhanced, due to the satellite's unique capacity to distribute signals over a vast geographical area. Direct broadcasting to home receivers from satellites is anticipated around 1980, which will open up a completely new era in educational and public affairs broadcasting.

CHAPTER 10 - BIBLIOGRAPHY

1. Campbell, R.R. and Honnold, G.H., "Teaching by Telephone", Bell Laboratories Record, Jan. 1970.

2. "Educational Radio", FCC Bulletin 21-B, April, 1971.

3. Jamison, D., Jamison, M., and Hewlett, S., "Satellite Radio: Better than ETV", Astronautics of Aeronautics, Oct. 1969.

4. Ofiesh, G.D., "Dial Access Information Retrieval Systems: Guidelines Handbook for Education", Final Report, July 1968, Contract No. OEC-1-7-071042-5093 for the U.S. Office of Education, HEW.

5. "The Hidden Medium: Educational Radio", Herman W. Land Associates, April 1967, prepared for the National Association of Educational Broadcasters.

6. Zazzaro, J., "They've Almost Invented Instant Learning", American School Board Journal, Sept. 1968.

Chapter 11 - Audio/Visual Systems

The advent of video communications technology in general, and television in particular, has increased the possibility of a host of educational applications by orders of magnitude. With the capability of remotely-located students to receive visual as well as aural information, simulation of classroom environment has been advanced drastically, although there still remain some admitted shortcomings.

Since, in most A/V systems, the audio information is transmitted by components and techniques already described in Chapters 3 and 10, the emphasis in this chapter will be on the visual elements of the systems reviewed.

An arbitrary classification has been used to categorize A/V systems, in accordance with the dynamics of the visual images being transmitted:

(1) Static - no motion of the visual image with respect to time or space, so far as the viewer is concerned (maps, still photographs, pages of a book, diagrams, etc.)

(2) Quasi-Static - some motion within the image but at a relatively slow rate, compared to normal motion picture or TV images.

(3) Motion - any degree of motion in the image, up to the limitations imposed by equipment.

As is usual with systems of any complexity, there are numerous cases of overlap among these three categories. A standard TV system, for example, can handle images in any of the three, but it is much less efficient for the first two.

Examples of specific operating systems have been selected, as in the audio case, to be illustrative rather than comprehensive. They range, chronologically, from educational TV broadcast and CCTV systems over 20 years old, to recent ITFS installations (Stanford, 1969),pilot demonstration of advanced retrieval techniques (TICCIT, 1971), and some systems more conceptual than actual.

As contrasted with purely audio systems, A/V educational applications (including the computer-based systems reviewed in Chapter 12) are still in their infancy, with an anticipation of rapid growth in this decade.

11-1 Visual/Static Systems

The transmission of visually static information generally occurs (at least in educational applications) either in connection with the reproduction of photographic and documentary material, or the display of computer-generated information. In the former case, the material can include maps, slides, still photographs, graphs, pages from a book or magazine, or microforms of any type.

Almost any of these visual images can be artificially generated by appropriate computer-programming. The difference between the two cases, therefore, is not in the final display that the viewer sees but in the relative requirements for databank storage and control. As an example, computer-generated displays are possible with an all-electronic system, whereas retrieval and transmission of microfilm images require electromechanical and electro-optical retrieval and conversion. The desired image must be selected from the microfilm file , and mechanically brought into conjunction with a scanner which will convert the stored photographic information into electrical form for transmission.

This scanning is in effect a facsimile process. Electronic scanning via a video camera is also possible, and may utilize either slow-scan or conventional TV, with better cost-effectivity for the former.

Where the information is computer-generated, no photographic-to-electronic transformation is necessary. Further, the electrical format of the information can be more flexible, and made to adapt to a variety of transmission systems and display devices.

11-1.1 Facsimile - Based Systems

Facsimile as a concept is particularly attractive in retrieval systems where remote hard-copy reproductions are necessary. Its utilization, however, in education has been rare because of the relatively long transmission times required, and the consequent high cost of telephone line facilities.

With respect to education, one point is of particular interest. The limitations of speed and cost introduced by the telephone-line communications link largely disappear when in-house systems are considered. For example, a university campus installing facsimile transmitters and receivers only within its grounds could use larger-diameter hard copper wire (or, at more cost, coaxial cable) as a direct-connection replacement for the telephone-line communications portion of the system. This would provide two benefits:

1. Eliminate line charges (which are the most significant load-variable factor).
2. Permit communications at perhaps four times the phone-line rate due to the greater bandwidth of the copper wire.

Thus, both a time and cost saving are achieved concurrently, which is certainly attractive. The limitation is that such a direct-wired system is limited to distances of a few miles before requiring signal amplification. Thus, direct-wired school-to-home applications are not feasible economically.

An illustration of a facsimile-based microfilm retrieval and delivery system which is a combination of available components and subsystems is shown in Fig. 11-1. Eastman Kodak provides an automated microfilm storage and display system called "Miracode" which, upon pushbutton request by an operator will display upon an illuminated screen an enlarged version of any 16mm microfilm frame stored within its files.

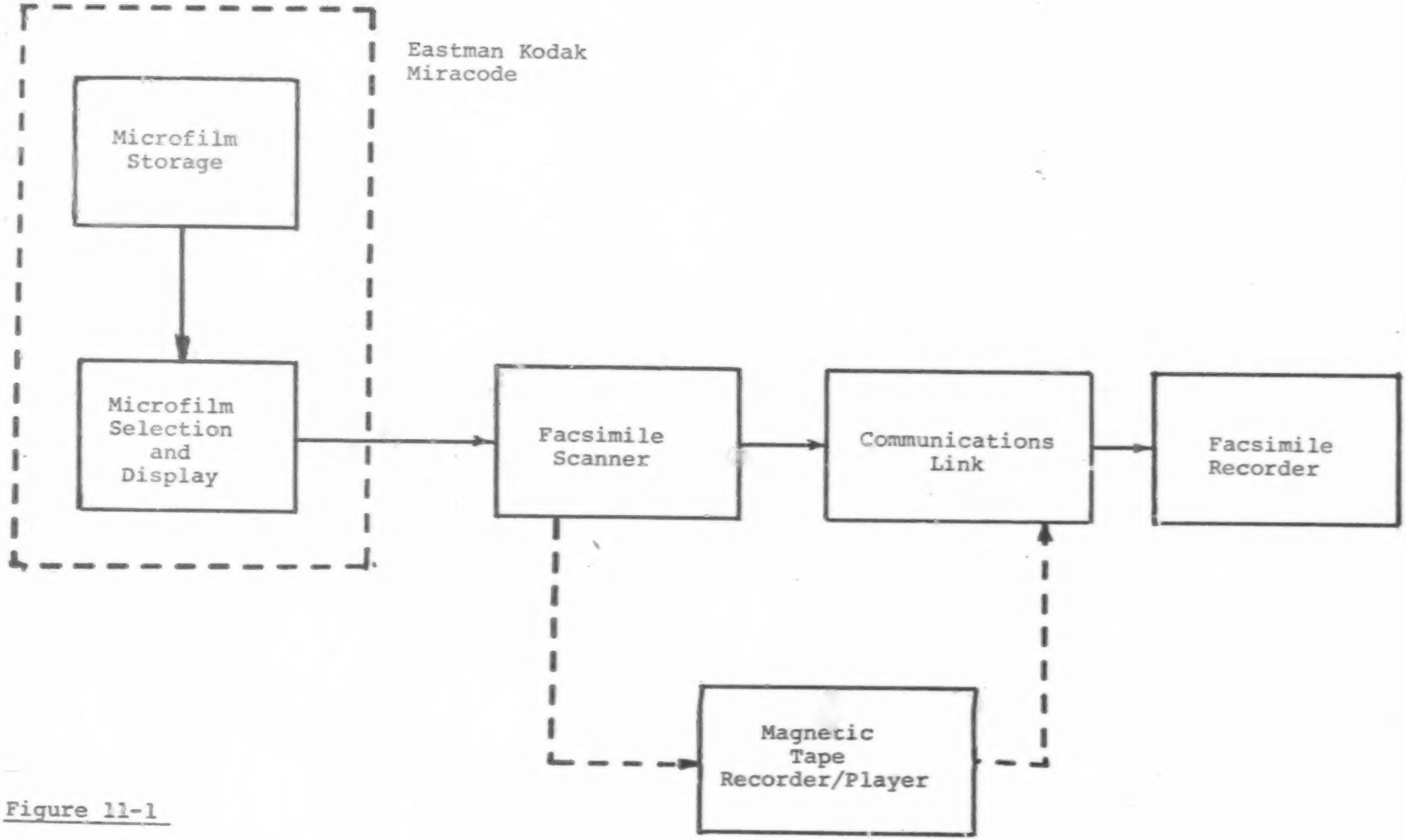

Eastman Kodak
Miracode
Microfilm Storage
Microfilm Selection and Display
Facsimile Scanner
Communications Link
Facsimile Recorder
Magnetic Tape Recorder/Player

Figure 11-1

Facsimile-Based Microfilm Retrieval System

A facsimile scanner is located so that it is optically coupled to the display screen. Energizing this scanner produces as its output the electrical signal representing the scanned microfilm image. This is communicated to the remote facsimile recorder(s).

A magnetic tape recorder is utilized as an intermediate storage or communications interface device. Recording the image and playing it back at a faster tape speed, for example, will transmit at a higher rate, if the communications link provides sufficient bandwidth to do this. Reversing the process and playing back at a low speed permits the use of a low-cost, narrow bandwidth link, but consumes more time in transmission.

A system as shown in Fig. 11-1 requires practically no special development, since all elements are commercially available. Its cost-effectiveness for educational applications, however, remains to be demonstrated.

As an illustrative example, the U.S. Postal Service recently announced the initiation of facsimile mail service on November 1, 1971, between New York and Washington. The service is designed primarily for the transmission of important business documents, such as legal briefs, bids, contracts, etc. The cost will be $4.25 for the first page and $3.00 per subsequent page if picked up in the lobby of the receiving post office, or an additional $1.00 if delivered. While use by the Postal Service certainly lends prestige to facsimile, the service offered has been variously predicted and discussed some ten to fifteen years. In its present form, it offers no new technical advance, and the cost, while not exorbitant, certainly removes the service from the majority of non-urgent applications, including education.

In the near future (possibly the next five years), the growth of information storage and retrieval centers designed to be accessible by the public may stimulate facsimile technology. The "dial a document" concept, in which the user dials the phone number of the retrieval center, enters the code for the desired document, and has it located and scanned by facsimile, producing a printout at his receiver, may become operational. The barrier to implementation still will be the relatively high transmission and terminal cost, so that pressure will be exerted for technological solutions. Initial installations will probably be in universities and schools, where the libraries might act in this capacity, transmitting requested pages of books, reports, test papers, etc. to faculty and student recorders. (This concept was planned for the new University of California, Irvine,campus.) For such in-house systems, the elimination of phone lines could make the system economically justifiable. When broadband communications networks supplant the ubiquitous telephone line (perhaps within a decade) facsimile will have to operate at correspondingly higher speeds. This probably will dictate all-electronic scanning and printout, merging facsimile and slow-scan television together, possibly into only one survivor.

11-1.2 TICCIT, an Interactive Page - Retrieval TV System

An interactive page-retrieval TV system called TICCIT (Time-shared Interactive Computer-Controlled Information Television) has been developed by the MITRE Corporation and is being demonstrated on a pilot basis, in conjunction with a cable TV system in Reston, Virginia.

TICCIT provides computer-generated or computer-controlled information that can be selectively received and displayed by standard TV receivers. The information is displayed in visual/ static form, e.g., a page of text, a graph or a photograph.

In standard TV transmission, as has been noted, a new picture frame is sent to the receiver 30 times per second, allowing moving images to be presented without noticeable flicker. Each frame is made up of 2 interlaced fields, so that fields are transmitted 60 times a second. Even when still pictures are transmitted, the same picture fields are repeated over and over at the 60 per second rate. Thus, TV, which is designed to present moving images, is repetitively wasteful for non-moving images.

What TICCIT essentially does is "slice" time into small intervals, and during each interval, transmit only a single image as the equivalent of a TV field. Further, this image is directed to only one TV receiver by means of an addressing technique which permits that receiver and no others to receive it. At the receiving site, local equipment provides the "repeat" or "refresh" function, i.e., recording the image and playing it back 60 times a second into the TV set. Thus, the image is compatible with the TV set's requirements, and the display is maintained without fading on the TV screen, while during this time the transmitter is sending other images to other selected receivers.

In the prototype TICCIT system, a new message can be sent to any particular TV set as often as once every 10 seconds. Comparing this to the normal 60 field per second rate, it is evident that 600 separate pictures can be transmitted in a 10-second period. Thus, one standard TV channel can be time-shared to serve up to 600 viewers, each of whom could receive requested visual information which is displayed for 10 seconds and then replaced.

As an example, if a viewer wishes to read a book or report, he can call for and receive a page each 10 seconds.

Figure 11-2 shows the basic elements of the TICCIT system. An information storage bank stores all of the information the system is capable of delivering. Upon request from a home terminal, the computer will call for the selected information and control the manner of its being fed into the communications link. An "address" is generated in the form of unique code so that only one home terminal can receive the requested information. This process is repreated concurrently for up to 600 home terminals, with the computer "directing traffic".

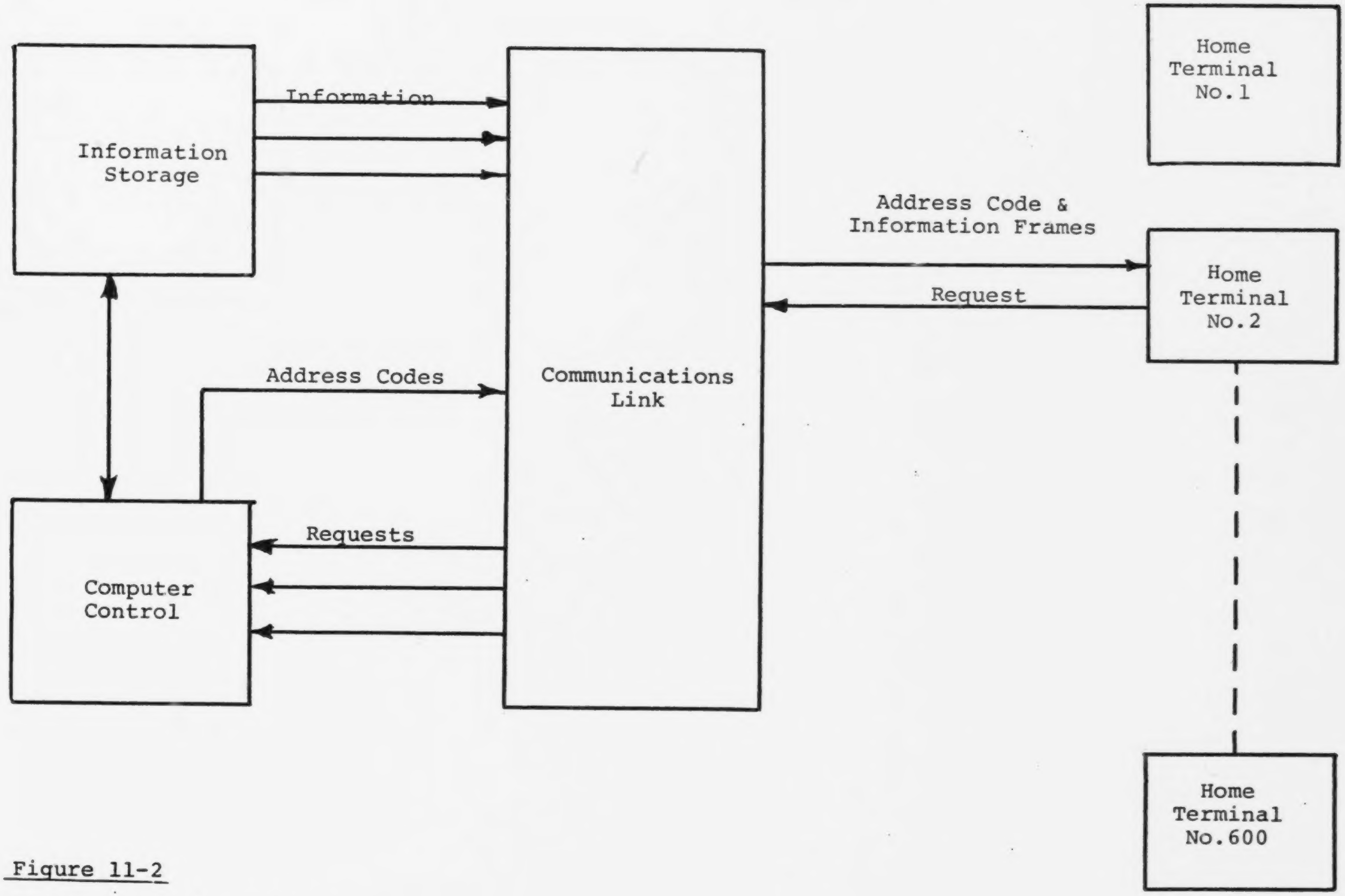

Information Storage
Computer Control
Communications Link
Information
Address Codes
Requests
Address Code & Information Frames
Request
Home Terminal No.1
Home Terminal No.2
Home Terminal No.600

Figure 11-2

Block Diagram - TICCIT System

In the Reston demonstration, the communications link is a channel of a CATV cable system operated by the Reston Transmission Co. The cable link is a particularly good match to TICCIT, since it already connects into each home and can transmit signals without the need for FCC broadcast frequency authorization.

The computer facility is an existing installation operated by MITRE in McLean, Va., with special software to demonstrate TICCIT capability. Telephone-line modems are also added to accept requests from home terminals (which utilize Touch-Tone telephones to initiate requests) and translate those into computer-understood language.

Each picture sent out carries with it an "address" of the designated home terminal. Addresses are coded as a sequence of 16 black or white elements along the last line of each transmitted picture. Each element is in effect a black or white bar on the line, measuring 1/16 of the total line length. With 16 elements, up to 64,000 unique address combinations are possible, using binary coding.

Possibly the most important component in the TICCIT system is the home terminal, since low cost and relative simplicity are vital for mass acceptance. Fig. 11-3 illustrates the terminal equipment used in the Reston demonstration. This includes, besides the TV receiver, a special computer-decoder unit, a video tape recorder and a Touch-Tone telephone.

When the switch shown is in the "TV" position, the TV receiver receives conventional TV signals from the CATV coaxial cable. When, however, the switch is set to the "TICCIT" position, the retrieval mode is activated.

The Touch-Tone phone is used as the request/data entry device. The phone number for the computer is entered, and the computer, in response, signals with a beep tone when ready. It sends to that viewer's screen a display which lists the "directory of services", i.e., what information is available.

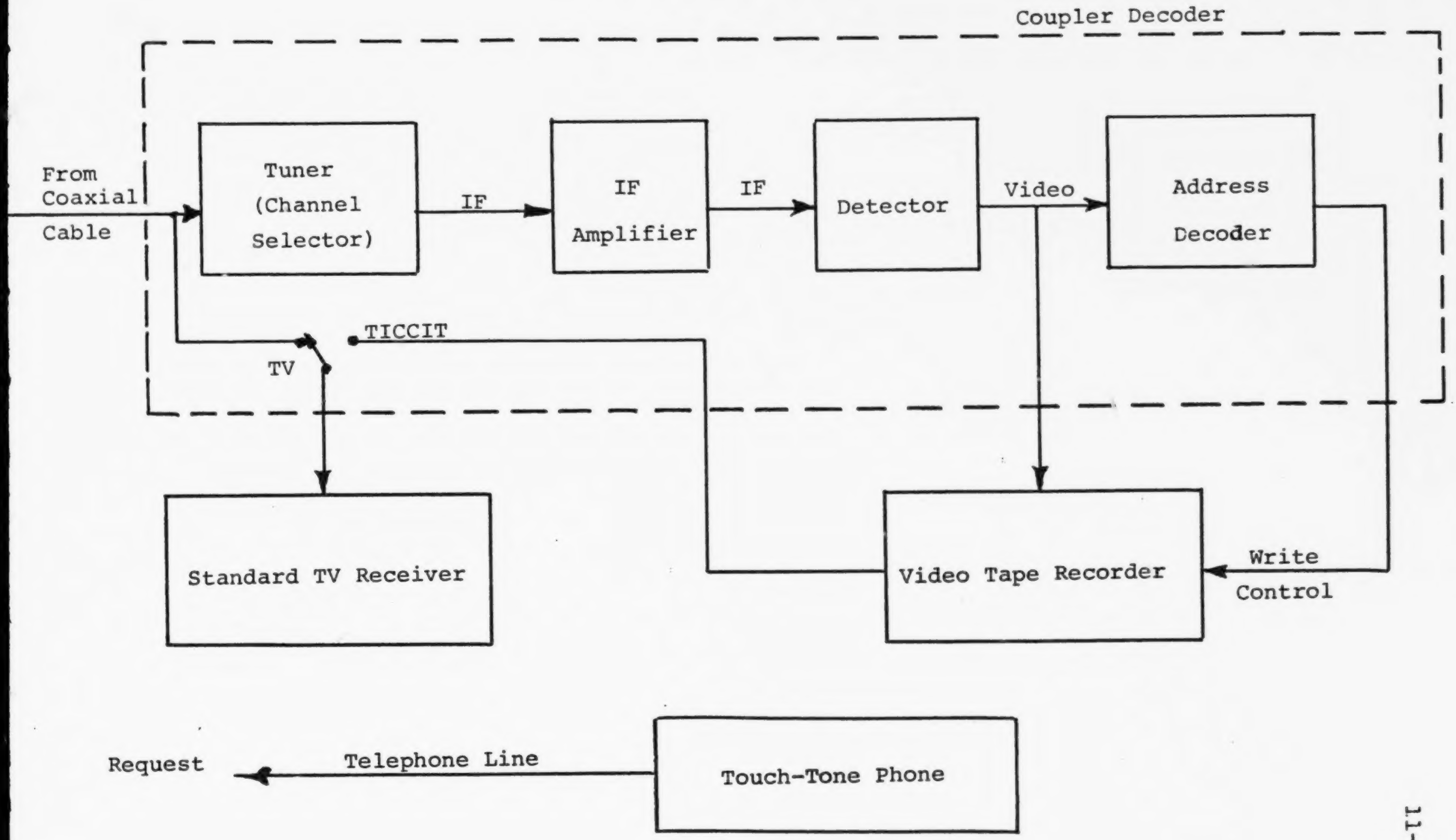

Coupler Decoder
From Coaxial Cable
Tuner (Channel Selector)
IF
IF Amplifier
IF
Detector
Video
Address Decoder
TICCIT
TV
Standard TV Receiver
Video Tape Recorder
Write Control
Request
Telephone Line
Touch-Tone Phone

Figure 11-3

TICCIT Home Terminal (Demonstration System)

The viewer then enters a code on his phone by pushing the appropriate button corresponding to the information he wishes to view, and the computer initiates the sequence of display frames to be sent.

The computer also identifies the phone which made the request, and generates an address code for that terminal. This address, as noted, is added to the picture signal as a part of the line-scan pattern.

The information requested (along with all requests from other terminals, time-sequenced 600 to a 10-second period) enters the coupler-decoder unit from the CATV cable. The first portion of the coupler-decoder is identical to the input portion of a TV receiver (compare Fig. 4-8), and serves only to separate the video signal from the RF carrier.

The video signal, representing the image to be displayed, is recorded on a video tape recorder of the helical-scan type. As has been pointed out in Chapter 4, most VTR's of this kind will record 1 track in 1/60 second. Ordinarily, after this interval, the tape is moved so that the next adjacent track is recorded.

If, however, the tape take-up and supply mechanism is disabled, the VTR may be used to record for 1/60 second and then, by switching to the playback mode and retracing the recorded track over and over, play the same information back each 1/60 second continuously thereafter. Thus, the VTR becomes an ideal "frame-grabbing" or refresh device.

The VTR continues to play back the information display to the TV receiver, so that the display is maintained, flicker-free, for the 10-second period, after which a new frame is received from the cable.

The address decoder section has the function of "looking at" the line of the display which contains the designated address. If this incoming address matches a unique address code which has been preset into the decoder, then and only then will the VTR be instructed to proceed to record and playback. Thus, even though messages are being sent over the party-line cable continuously, only those requested will be displayed.

It is acknowledged that the current cost of VTR's is too high to make TICCIT immediately applicable to a mass audience. The other two components of the home terminal, the Touch-Tone phone (which usually would already be available), and the coupler-decoder (which, in quantity, can be produced in the $50 range) are relatively inexpensive.

The assumption is that with the advent of cassette video recorders, in both black-and-white and color, the price of this element will eventually drop drastically and thus make a full-scale TICCIT system economically feasible. Another alternative would be the development of a special-purpose low-cost refresh device using techniques other than video tape recording.

A major factor in determining TICCIT's eventual success is the development of a library of software, i.e., visual material of interest to viewers and in the necessary computer-compatible form. The Reston demonstration software consist of two relatively elementary arithmetic exercises, one designed to teach children to add 2-digit numbers, and the other a drill-and-practice course in fourth-grade arithmetic, designed by the Computer-Aided-Instruction Group at Stanford University.

Obviously, there is complementarity and mutual support between CAI and TICCIT-type systems. The generalized TICCIT concept, however, is broader, permitting any kind of selective information retrieval.

11-2 Quasi-Static Visual Information

A substantial amount of visual information pertinent to education falls into the quasi-static category, i.e., images which change at a slow rate. An example would be the material written on a blackboard or a pad by a teacher.

Since the information is not usually in document form, and is varying with time, facsimile cannot be used as a telecommunication technique. Similary, frame or page-retrieval systems described above are also not applicable, since they require static images.

On the other hand, conventional TV is "over-designed" for quasi-static material, and is inefficient in terms of bandwidth utilization and equipment cost.

As a result, hybird approaches have been developed which use low or medium (voice-grade) frequency communications links to transmit visual data. The quasi-static nature of the data makes the use of limited-bandwidth transmission feasible.

Examples of this approach are described below.

11-2.1 Blackboard-by-Wire

Many schools and colleges transmit audio and quasi-static visual information over telephone lines to remote locations by systems variously termed "blackboard-by-wire", "remote blackboard" or "electronic blackboard".

Two typical systems are manufactured, respectively, by Sylvania and Victor Comptometer. The Sylvania system (formally the ECS-100 Educational Communications System) enables groups of students in remote locations to hear a lecturer and simultaneously view his graphic material as it is presented.

The instructor speaks into a microphone at his desk, and the audio information is transmitted over a phone line to each remote location in a conventional manner. At the same time, he writes or draws with an electronic stylus pen on a 6" X 8" roll-up pad which is part of a desk-top graphic transmitter. The X-Y components of the writing motion are coded into electrical signals, converted to FM form in the voice-band below 3KHz, and transmitted over a phone line also. Either separate audio and visual phone lines may be used, or the two combined on one line.

The visual information is received at the remote classroom by a graphic receiver which includes a decoder, a CRT storage display unit, and a video camera. The FM signals are demodulated and used to generate a display on the screen of a long-persistence

CRT, selected so that the relatively slow moving image does not fade too soon.

The video camera photographs the face of the CRT, and converts the image to a signal capable of being displayed on a standard TV receiver in the classroom. Thus, the small CRT image is effectively enlarged so that it may be viewed by the entire class.

The Victor system (Victor Electrowriter Remote Blackboard, or VERB) accomplishes essentially the same task. In the receiving portion of the system, however, an electronic stylus pen, similar to that at the teacher's desk, is used to retrace the image on transparent acetate paper. The image is then, like a "view-graph", projected onto a screen anywhere from 3' X 5' to 9' X 12', for immediate viewing by the class.

The cost of blackboard-by-wire transmitting and receiving equipment is relatively moderate, and for some remote locations may be the only realistic choice. Apart from the physical limitations imposed on the instructor (i.e., he must restrict his activities to the proximity of the microphone and writing tablet), it is important to realize that in many cases, the major costs will be telephone line charges. These should be estimated accurately before a total system cost can be arrived at.

There is no technical reason why wireless (radio) transmission could not be used instead of telephone lines, but the requirement for FCC broadcast frequency allocation mitigates against this approach.

11-2.2 Slow-scan TV

Slow-scan TV is the generic term for systems which transmit visual information by using the line-scanning techniques of conventional TV, but at a much lower transfer rate. Thus, narrower bandwidth communications links, even telephone lines, can be used.

An example is the Picturephone system under development by A.T. & T. This scans 30 frames per second, and has 2 interlaced fields per frame exactly similar to TV, giving a flicker-free image since the eye does not notice a flicker rate of 60 per second. However, only 250 lines make up a frame (less than half of TV's 525) and the resolution along each line is poorer. Consequently, a total bandwidth per Picturephone channel of only 1 MHz is adequate, compared to the 4-1/2 - 6 MHz used for TV.

This is satisfactory for the purpose, since Picturephone screens generally will not be required to display rapidly-changing images. For quasi-static information, even narrower bandwidths than 1 MHz can be used, by reducing still further either the number of lines per frame, the number of frames per second, or both.

If reducing the number of frames per second might result in flicker at the display, either CRT's with longer persistence screens can be used, or a local refresh unit, such as that for the TICCIT system, be incorporated into the receiving terminal.

Slow-scan TV can be accomplished also by not transmitting in real time, i.e., taking a longer time to transmit visual information. As an example, if a school desires to transmit a video taped TV program to a remote location for viewing at a later time, there is no necessity for a wide-band video channel. Theoretically, it can play back the tape at 1/10 the speed at which the program was originally recorded. Thus the 6 MHz TV bandwidth is effectively reduced to 600 KHz and a narrower-band communications link could be used. The penalty paid is in transmission time, so that a 1/2 hour program would take 5 hours to transmit. This is feasible, however, and the sending facility might transmit at night to a video tape recorder at the receiving facility. The next morning, by playing back at 10 times the speed of recording, the program can again be viewed in real time.

This technique for compressing or expanding bandwidth vs. transmission time is, of course, subject to the dynamic ranges of available equipment, and thus has definite limits. In concept, however, it is extremely flexible, especially where the visual information does not have to be viewed directly.

11-3 Visual/Motion Systems

To date, almost all visual/motion systems using telecommunications for educational applications have been television-based, i.e., the user's terminal has been a TV receiver. Film and slides have been utilized for many years, of course, but usually in direct projection within a classroom or auditorium. If transmitted remotely, the film would be converted, first to electrical signals and subsequently to a TV display.

The commercial TV broadcast industry has established the basis for system performance and technical specifications, and it has been simpler and less costly for educators to adapt to these than to design special-purpose systems which require development time and funds. The availability of a good-quality black-and-white TV receiver for \$150-\$300, or a color unit for \$300-\$600, is possible only because of their mass production for the entertainment market.

In some respects, the commercially available TV equipment is not always suitable for specific educational objectives. It was noted, for example, in the TICCIT system that a separate "frame-grabbing" refresh unit was necessary to keep the picture steady on the TV screen. In that case, a VTR, costing perhaps \$1,000 (certainly more than the TV receiver) was used, admittedly as an expedient. If a TV receiver were available with a built-in refresh feature, which can be accomplished at relatively low cost, a much simpler, more practical system would result. Since there is no requirement for this feature in commercial TV, however, it has not been developed. Moreover, the relatively small educational market, at least at present, implies that it will probably not be developed in the near future.

Thus, educators must keep in mind the constraints of commercial TV equipment, and generally live with these constraints. Innovative applications, however, will often require equipment not normally available. In some cases, modifications can be made at reasonable cost.

11-3.1 Educational/Instructional Television (ETV/ITV)

"Educational Television" (ETV) is generally defined as the delivery of audio/visual material, intended for educational purposes, to an audience by means of television. "Instructional Television" (ITV) has a narrower focus and is intended to provide instruction in a specific subject, e.g. French, arithmetic, etc. ITV may be considered as a subdivision of ETV which includes broader aspects such as cultural and social topics.

From a technological point of view, however, in which the content of the program material is not considered, there is no difference between ETV and ITV. Indeed, the differences among any television-based educational systems lie primarily in the methods of transmission and distribution, with the source and reception subsystems being almost identical.

Three delivery techniques are currently used to distribute educational television material:

(1) Broadcast TV - in which the TV program is broadcast from VHF and UHF transmitters through the air to standard home TV receivers. Any receiver within the geographical broadcast area can receive the program, so that there is essentially no selectivity of audience.

(2) Closed-Circuit Television (CCTV) - which transmits the TV material over a special wire communications and distribution network which limits the audience

to those physically connected. Usually no over-the-air broadcasts are involved, although point-to-point microwave communications links may sometimes substitute for a portion of the cable network.

(3) Instructional Television Fixed Service (ITFS) - which really is a form of broadcast TV, but deserves special classification because of its designation for educational use. ITFS utilizes a microwave broadcast frequency band (2500-2690 MHz) assigned by the FCC for instructional purposes only. Broadcasting occurs under sharply limited power conditions, and reception requires special conversion equipment, which effectively restricts the audience to a selected group.

11-3.1.1 Broadcast and CCTV Systems

A generally used, ETV refers to the broadcasting of educationally-oriented programs by FCC-licensed stations operating in the standard VHF and UHF frequency bands, assigned to television. The difference between ETV and commercial TV broadcasting lies in the program content and method of financing operations, rather than in technology or equipment.

Television stations devoted to educational material exclusively have existed for almost twenty years, with, for example, KVHT beginning operations in Houston in 1953. Since that time, more ETV stations have begun operation, sponsored or financed by state education agencies, private foundations, universities and colleges, or non-profit corporations relying on audience and subscriber contributions.

By the end of 1970, a total of 198 stations (85 VHF and 113 UHF) were on the air. Estimates are that these stations provide coverage to about 75% of the U.S. population, with only the states of Alaska, Montana and Wyoming not containing an education/public TV station. It is also estimated that an average of 33,000,000 people view at least one ETV program each week.

The growth of educational broadcasting was stimulated sharply in 1967 when Congress, following the recommendations of the Carnegie Commission on Public Television, enacted the Public Broadcasting Act. A "public corporation", named the Corporation for Public Broadcasting (CPB) was established and charged with the following tasks:

- Facilitating the development of educational broadcasting by making available suitable program material to non-commercial educational stations.
- Assisting in the establishment of one or more systems of interconnection (networks) for the simultaneous distribution of programs.
- Assisting in the expansion of one or more ETV and radio systems throughout the U.S.
- Operating so as to assure maximum freedom for local stations, either from interference with or control of program content or other activities.

Funded partly from the Federal Government and partly from foundations and private grants, CPB has achieved, in 1969-70, the initial formation of both an ETV and educational radio network. The former, termed the Public Broadcasting Service (PBS), achieves interconnection through a system of leased common-carrier coaxial cables and microwave links.

Technologically PBS is simply a fourth TV network devoted to educational/public programs. (The term "public broadcasting" is now used officially by CPB to supplant "educational broadcasting", to indicate a range of programs touching the cultural and social levels as well.)

Local ETV stations can accept the network's program offering or utilize material from other sources. As with commercial TV, the limitation on programming funds and personnel usually forces most local stations toward acceptance of network offerings.

Fig. 11-4 indicates the basic elements of a broadcast TV system, whether educational or commercial.

A majority of ETV stations operate in the UHF band. Although modern TV receivers can receive the UHF spectrum, reception in most areas in poorer than for VHF, with an adverse effect on the size of the audience. The continuous-type tuner used to select UHF stations is also more difficult to adjust properly than the UHF rotary-switch tuner, providing a further handicap. Still another disadvantage is the generally lower transmitter power levels of VHF stations, reducing geographical coverage.

Other than these problems (which are true for non-educational UHF stations as well), the limitations on ETV are primarily financial rather than technological.

A number of ETV stations have allocated some broadcast time (usually in the early morning or late evening, to minimize the impact on their general audience) to ITV, designed to furnish specific instruction in selected subjects. The broadcasting of ITV from ETV stations suffers from the inherent disadvantages of a 1-channel facility:

- the necessity to broadcast at inconvenient times
- the difficulty in reaching, holding and/or measuring the desired audience
- the probability of only a small percentage of the total audience being interested in the ITV material.

For these reasons, the availability of ETV broadcast time for ITV purposes may not in itself be responsive to instructional objectives.

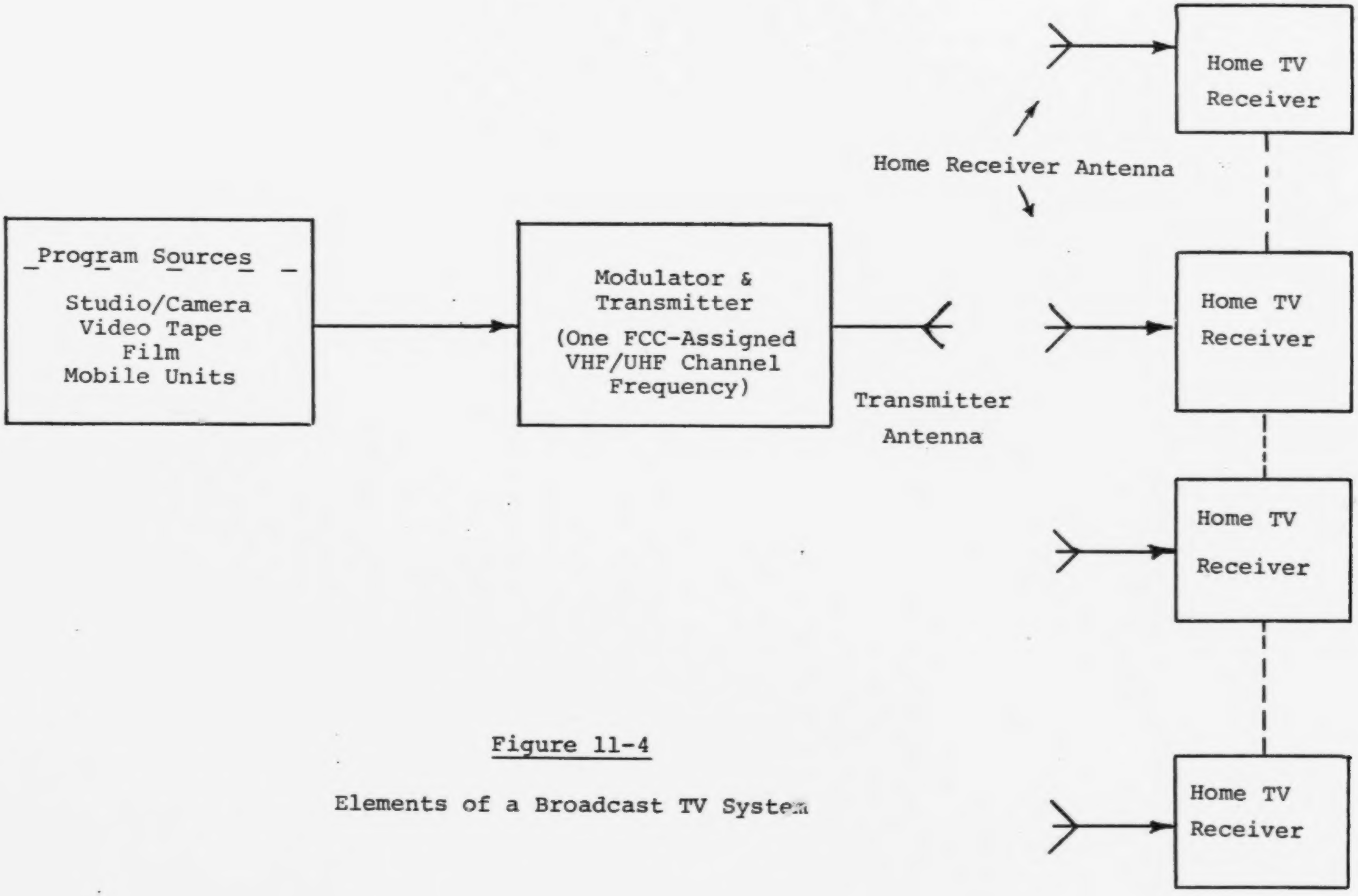

Program Sources
Studio/Camera
Video Tape
Film
Mobile Units
Modulator & Transmitter
(One FCC-Assigned VHF/UHF Channel Frequency)
Transmitter Antenna
Home Receiver Antenna
Home TV Receiver
Home TV Receiver
Home TV Receiver
Home TV Receiver

Figure 11-4

Elements of a Broadcast TV System

In the next three to five years, even before domestic communications satellites are operational, it is expected that networking of ETV stations will increase, in terms of more comprehensive interconnection of transmitters via common-carrier cable/microwave facilities. Most ETV/ITV stations should have the option of using either network or local programming by 1974-75.

CATV systems proliferation will increase audience coverage, since almost all new CATV franchises not only deliver a better quality picture for UHF channels than is available off-the-air, but in many cases also bring non-local ETV channels into their subscriber community if feasible.

Closed-circuit systems (Fig. 11-5) differ from the diagram of Fig. 11-4 only in that the wireless broadcasting portion (transmitter, antennas, air medium) is replaced by a network of cables and auxiliary equipment necessary to force the television signals through the network to the receiving locations. Cables may be common-carrier or user-owned.

CCTV is a fully controlled distribution system with all receivers identified, and total exclusion of non-participants. Further, no FCC broadcast frequency assignments are required since no radiation outside the cables takes place.

Coaxial cable transmission systems may be either video or RF. In the former, picture signals are transmitted in the same frequency range (0 - 4.5 MHz) as they emerge from the video camera chain. The associated sound is usually transmitted separately over a twisted wire-pair paralleling the coaxial cable. A system such as this is used only where transmission distances are short and where a cable can be restricted to one TV channel.

In an RF system, more commonly used, the original video and audio frequencies modulate a radio frequency carrier wave, which is then sent over the cable. Many TV programs, each on its own separate RF carrier, can be transmitted simultaneously on the same coaxial cable.

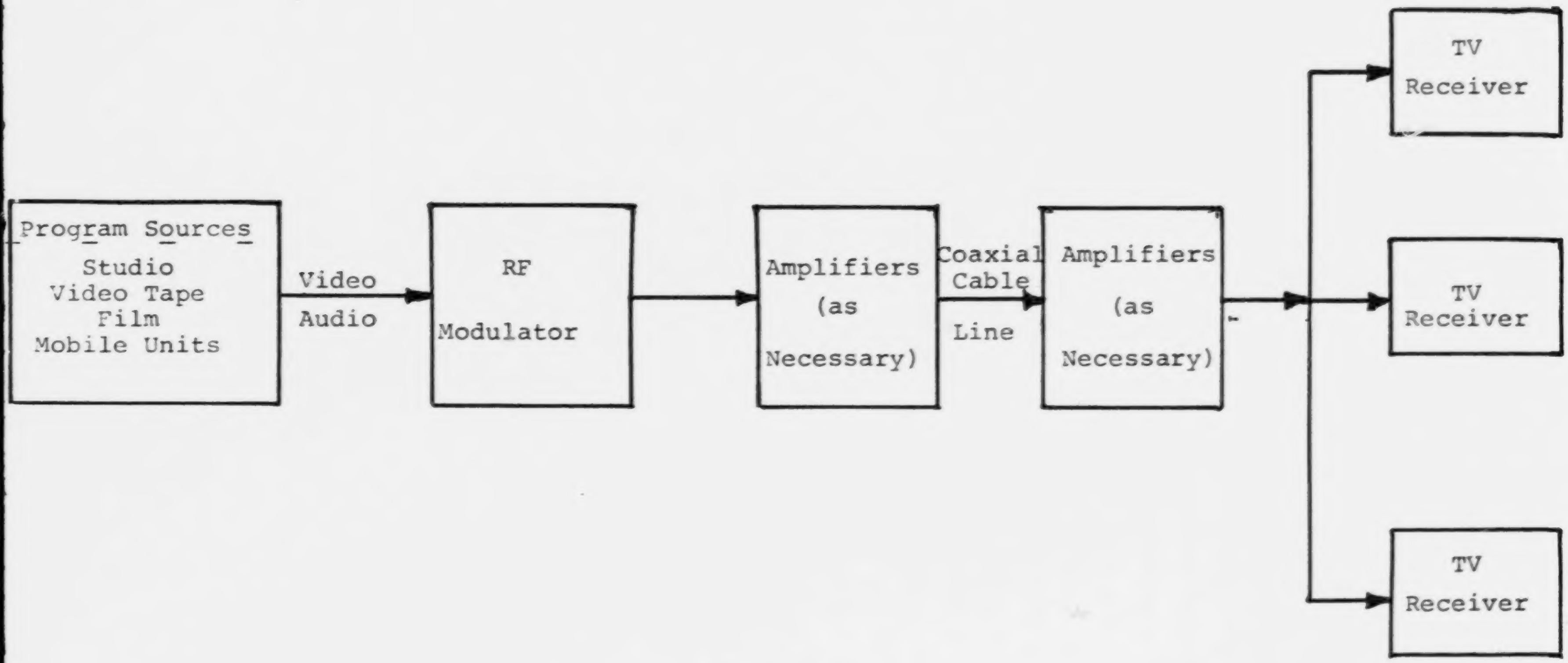

Program Sources
Studio
Video Tape
Film
Mobile Units
Video
Audio
RF
Modulator
Amplifiers
(as
Necessary)
Coaxial
Cable
Line
Amplifiers
(as
Necessary)
TV
Receiver
TV
Receiver
TV
Receiver

Figure 11-5

Elements of A CCTV System

The closed, controlled (both as to audience and programs) nature of CCTV, plus the availability of multichannel distribution over the cable, leads to many educational applications, particularly where maintaining autonomy and control of the curriculum at the local level are desired. Several hundred CCTV systems are now in operation by educational institutions throughout the U.S., with the oldest dating back to the late 1950's.

Since CCTV technology and equipment are tied to broadcast TV standards which have been stable for over 25 years, the technological changes have been evolutionary, and in general related only to improvements in performance/price ratio. Modern hardware such as CCTV video cameras may be smaller and cheaper, but not significantly different in performance from the first solid-state units made years ago. CCTV systems installed some 20 years ago or more are still operating satisfactorily.

Those areas where CCTV technology has advanced involve applications, particularly in semi-automatic program retrieval systems. A number of "dial-a-program" systems are in operation, combining dial-access with programmed retrieval of audio-visual material. These represent, in a sense, an expansion of CCTV techniques, and, indeed, could function only within a self-contained wired system because of the variety of programs distributed.

11-3.1.2 Audio/Visual Dial-Access

Audio dial-access systems have been discussed in Chapter 10, with the installation at Oak Park and River Forest High School used as an illustrative example. A logical expansion is the audio/visual dial-access system which can provide either audio programs alone, visual alone (slides, film strips) or the combined audio/visual program (television, film with sound).

The addition of visual material is more than just an incremental expansion, however. Since the bandwidth required for one TV channel is some thousands of times larger than for a voice communication, the costs of storing, switching and distributing video are correspondingly much higher.

Table 11-1 can be compared to Table 10-1 in this respect. Random access for some 10 video channels can cost 4-5 times the same capability for perhaps 100-200 audio channels.

The Oak Park and River Forest High School facility, has, in fact, been expanded to include video dial-access. This is "conventional" rather than random access, however, in that a student cannot instaneously obtain access to a program starting at its beginning, if the program is already in use. Instead he must wait until it is completed and can begin again, or be content to come in at whatever point the program is at.

The reason for this is the high cost of video random access. To dub a video tape at a high rate of speed is much more difficult and expensive than an audio tape, so the technique of providing a newly-dubbed "temporary" tape to any student making a request, as described in Chapter 10, is at this point prohibitive in cost for most educational institutions.

The "conventional" access technique at Oak Park and River Forest provides five video sources, a video tape recorder, a video camera and three film/slide chains. Thus, access is provided either to taped, live or film program materials.

Random access video, although expensive at present, is being planned for many future A/V dial-access systems. Figure 11-6 illustrates the elements of a random access A/V system. Comparing this diagram to Fig. 10-2 shows that a video duplication system has been added to the original audio. Thus, a dubbed video tape is made available rapidly in response to a student request. The video and audio information, moreover, are locked together by control circuitry so that they are always in synchronism.

Capability	Cost per Student Position ($)			Total Cost per Student Position
	Carrel	Switching, Control & Power	Program Source (Recorder/Player)	
Audio - random access, active and record	600	2,000	1,400	4,000
Video - tape playback, 1 channel only	Audio (above) plus 200	Audio (above) plus 200	Audio (above) plus 500	4,900
Video - tape, film or slide playback, 1 channel only	Audio (above) plus 300	Audio (above) plus 500	Audio (above) plus 1,000	5,800
Video - random access, tape, film or slide, 10 channels	Audio (above) plus 400	Audio (above) plus 4,000	Audio (above) plus 10,000	18,400

Table 11-1

Typical Equipment Costs - Dial-Access Audio/Visual System
(Estimated for 30-40 Carrels)

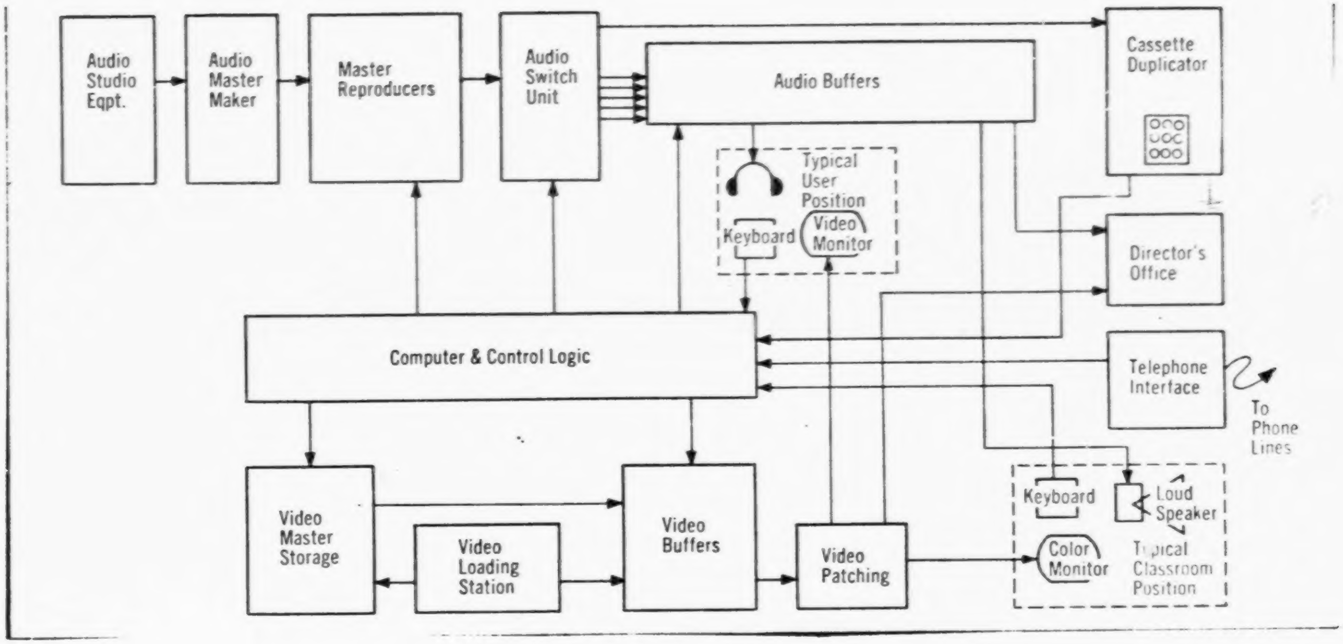

Audio Studio Eqpt.
Audio Master Maker
Master Reproducers
Audio Switch Unit
Audio Buffers
Cassette Duplicator
Typical User Position
Keyboard
Video Monitor
Director's Office
Computer & Control Logic
Telephone Interface
To Phone Lines
Keyboard
Loud Speaker
Color Monitor
Typical Classroom Position
Video Master Storage
Video Loading Station
Video Buffers
Video Patching

Figure 11-6

Random Access Audio/Visual System

The future of dial-access A/V systems (or "information retrieval television" as sometimes termed) appears bright if costs can be decreased, and if the programming task can be accomplished successfully.

There is no doubt that with the combination of a substantial program library and automated retrieval and playback, a major educational resource is established.

The present cost of such a resource undoubtedly will inhibit establishment on a widespread basis. Two major capital investment items are involved, the electronic hardware and the program library (software). Since either item can range upwards of $500,000 - $1,000,000 for a single facility, educational institutions find these systems difficult to fund within present fiscal constraints.

The issue of centralization vs. decentralization also emerges. Initially, decentralized in-house systems at universities, schools, etc. will be most practicable because broad bandwidth coaxial cable capable of carrying video signals need only be brought to carrels in the same building as the videotape library.

With the growth of CATV and satellite communications, however, resulting in broadband communications links to more homes, it may become more practical to have the program library (probably computer-controlled) at one or two central locations, thus reducing the physical volume of duplicate program material required.

11-3.1.3 The Stanford University ITFS Network

The ITFS network at Stanford University, in operation since 1969, offers a good illustrative example of using instructional television to reach off-campus students, while retaining a teaching environment closely simulating the on-campus classroom.

During the 1960's, graduate enrollment at the Stanford School of Engineering increased sharply compared to undergraduate, reaching a point where three times as many graduate students as undergraduates were enrolled. About 1/3 of the graduate engineering students were also employed, usually on a full-time basis, by various companies located throughout the San Francisco Bay and peninsula area.

Since no evening courses were offered at Stanford, the employed students had to be released by their employers for sufficient time to attend on-campus. This meant not only interruption of the work day, but also loss of time in driving and parking, which in many cases exceed the classroom instruction time. As an example, one large company calculated 2-1/2 man-years lost annually (which approximates a burdened cost of $100,000) just in the driving and parking alone.

The problem is intensifed if a student wishes to attend two courses given at different times, so that in many cases students would choose consecutive courses just for convenience, rather than suitability. Other potential students simply could not participate at all.

To attack this problem, Stanford initiated a feasibility study in 1967 to evaluate linking via telecommunications Stanford classrooms with "classrooms" located at each company's own facilities.

The objectives were to produce a remote learning environment approximating, as closely as possible, the Stanford classroom environment. To accomplish this, it was believed that 2-way audio communications were essential, but that video communications could be one-way without degrading the quality of instruction.

The study ascertained that the concept was technologically feasible, that the cost of operating the system would represent only about a 25% increment on tuition fees already being paid, and that a sufficient number of companies in the area would participate, both in the capital costs of the Stanford portion of the system and also in the reception facilities required in their own plants.

Some 40-50 industrial organizations participated with Stanford in sharing the system costs, in proportion to each one's size and utilization. Stanford applied for allocation of a band of 4 ITFS channels, and received authorization from the FCC.

A 4-channel ITFS network was installed in 1968-69, with the capital cost about $700,000 and annual operating costs in the order of $100,000.

Table 11-2 provides a summary of the characteristics of the Stanford ITFS system. Up to 4 separate TV signals from Stanford classrooms are cabled to an on-campus control room, then relayed via microwave link to a transmitter atop Black Mountain, 8 miles from campus. There the programs are translated to the 2500 ITFS MHz band and broadcast from 3 antennas.

Seven watts (of the available 10) are radiated from an omnidirectional antenna which covers an effective 20-25 mile range throughout the peninsula. To reach San Francisco, (35 miles), 1 watt is fed into a highly directive 10-foot parabola antenna, and 8-foot parabolas are used at the receiving sites. To reach the Berkeley area (39 miles away), 2 watts are fed into a 6-foot dish antenna, with 10-foot parabolas at the receiving terminals. Thus, the ITFS system is essentially an omnidirectional broadcast plus two narrowly directive beams aimed at specific point targets. A simplified video information flow diagram of the system is given in Fig. 11-7.

Originally, 2-way audio communications were achieved by using conventional dial-up telephone lines between the originating classroom and each remote classroom. The lines were connected into the audio portion of the TV system so that all students can hear any question or answer.

Apart from the generally marginal quality of phone-line audio links (susceptibility to noise, transients, limited bandwidth), the line costs are relatively high. A cost-effectiveness study at Stanford indicated that for 20-25 user companies in the San Francisco Bay area, and 4 audio channels

Stanford University ITFS System

Licensee	Board of Trustees, Stanford University, Palo Alto, California
Original Station	KCG-38
Relay Station	None
Number of Channels	4
Date of Application	4/68
Initial Operation Started	4/69
Staff:	
Full-Time	2 admin, 3 eng., 2 cler, 1 mgr., 1 courier
Part-Time	20 students
Transmitters	4 (Micro-Link)
Cameras	11 Video
Video Tape Recorders	15+
Film Chain	None
Projectors	One 16-mm, 5 slide
Mobile Units	None
No. of Studios	5
No. of Buildings	23+
No. of Classrooms with TV set	65
No. of Students	900
Operatings Hrs./Wk.	136
Radius	40 miles
% Local Programs	Above 75%
Program Types	Technical, Industrial, Panels
Total Capital Inv.	$700,000
Annual Oper. Budget	$100,000

Table 11-2

Stanford ITFS Features

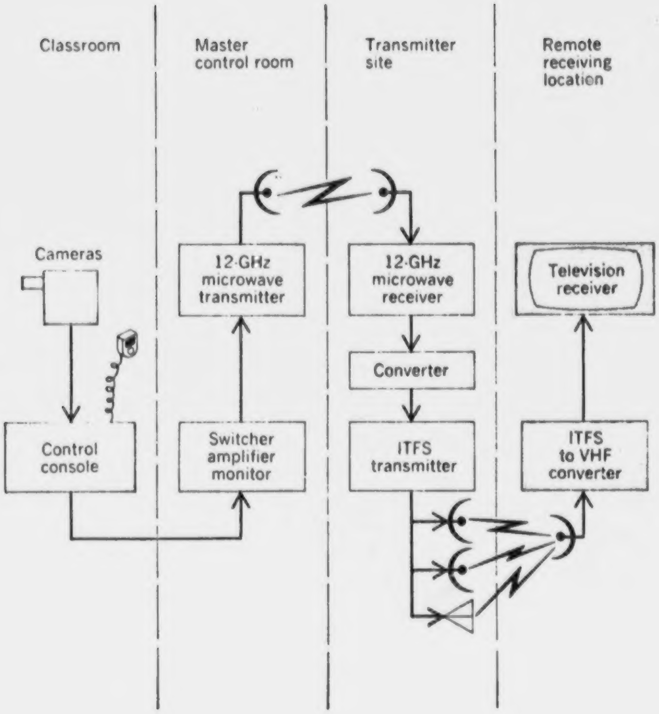

Classroom
Master control room
Transmitter site
Remote receiving location
Cameras
Control console
12-GHz microwave transmitter
Switcher amplifier monitor
12-GHz microwave receiver
Converter
ITFS transmitter
Television receiver
ITFS to VHF converter

Figure 11-7

Information Flow, Stanford ITFS System

per company, the use of FM radio for talk-back would cost about $1,000,000 less than phone charges, over a 10-year period.

As a result, Stanford petitioned the FCC to permit use of the upper end of the ITFS band (2686-2690 MHz) for FM talk-back purposes, and this was granted in June 1969. Within the 4 MHz band, the FCC allocated 31 channels (one for each TV channel in the ITFS spectrum), each 125 KHz wide, designated as ITFS Response Stations.

These FM audio channels supplanted the dial phone lines at Stanford. Each remote classroom is equipped with an FM Transmitter (switchable to any of the four allocated frequencies associated with the four video channels) and an antenna. The talk-back signal is directed to the Black Mountain antenna site, and relayed from there to the Stanford classroom as well as all remote receiving locations.

Functionally, the on-campus studio/classrooms are designed to resemble conventional classrooms as much as possible. A normal-size class is accommodated during the broadcast, so that the teaching environment basically is unchanged.

Each classroom (see Fig. 11-8) houses two video cameras, one over the instructor's desk and the other at the rear of the room. Both cameras have remote-controlled tilt-pan-zoom capability. The overhead camera is used for viewing written information generated by the instructor at his desk, or view-graphs, slides, etc. The rear camera can view the entire classroom, or provide close-ups of the instructor or the blackboard.

Monitor picture tubes and microphones are located throughout the classroom, one for each two students. By depressing a "push-to-talk" switch, the student's voice is picked up and can be heard throughout the system.

Associated with each studio/classroom is a satellite monitor room used for overflow of large classes, seminars or CCTV lectures. In addition, an auditorium has been equipped to handle panel events, large seminars, guest speakers, etc.

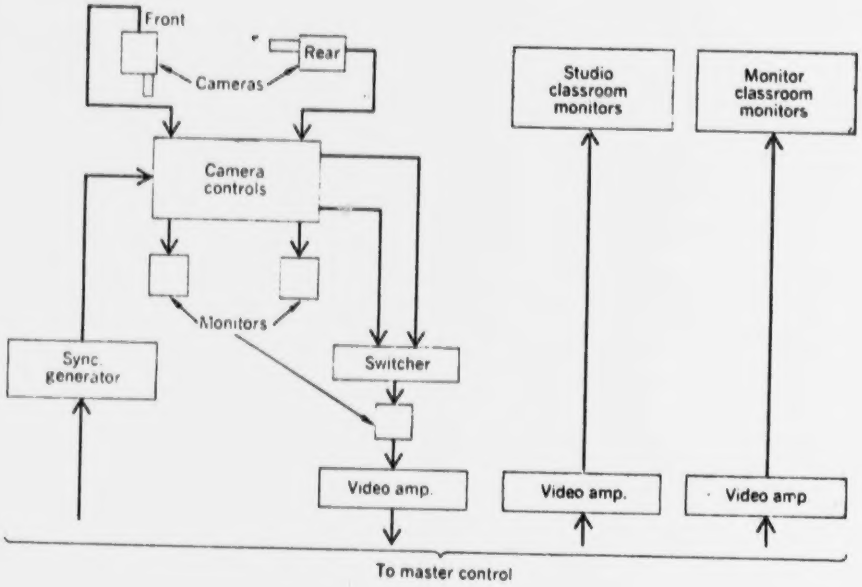

Front
Rear
Cameras
Studio classroom monitors
Monitor classroom monitors
Camera controls
Monitors
Switcher
Sync. generator
Video amp.
Video amp.
Video amp
To master control

Figure 11-8

Block Diagram, Studio/Classroom Equipment

The "operating staff" for each televised class consists of one student who operates the camera and audio controls, switching of cameras and the talk-back system. A licensed radio/TV engineer is present in the master control room to monitor system performance.

The receiving classrooms, located at each participating company, are equipped with one or more TV receivers and talk-back microphones. Appropriate ITFS receiving antennas and equipment and the FM talk-back transmitters are also necessary, although these are usually located external to the classroom. Stanford provides technical specifications and guidelines for receiving locations to assure system uniformity and compatibility.

As an adjunct to the instructional program, a courier from Stanford makes daily rounds to all participating organizations, delivering class notes and handout material, and collecting homework and examinations from the students. The Stanford honor code has been extended to the remote classrooms.

Participants are permitted to make video recordings of lectures for the sole purpose of student make-up and review, providing the tapes are erased within two weeks after the end of the term.

The costs borne by the participating companies are of three kinds. Initially, each company contributes a share of the capital costs associated with the total ITFS facility, with the share determined by anticipated usage. These capital payments have ranged from $2,000 for small companies to $40,000 for the largest.

Secondly, each company is responsible for equipping its own receiving facility and classrooms. This cost can vary from $10,000-$20,000.

Finally, there is a tuition charge for each student, on a "per unit" basis similar to that of on-campus registration. This includes fees to cover the normal academic departmental costs, and also the continuing operating expenses of the ITFS network.

11-3.1.4 Comparative Costs of Television Based Systems

Estimates of the cost of television-based educational systems can be highly misleading, unless the underlying assumptions in each case are understood precisely. For example, a broadcast ETV system may assume that TV receivers are already available to the intended audience and represent no added cost, whereas a CCTV or ITFS system aimed at specific remote classrooms in industrial facilities cannot make such an assumption.

The major elements of cost include:

(a) Initial Cost of Equipment and Facilities

(b) Initial Cost of Program Library

(c) Operating Cost of the System (Personnel, Maintenance, Communications Charges, etc.)

Of these, the cost of the software, the program library, is probably the most difficult to estimate, since this impinges upon educational rather than technological factors, and there may be wide disagreement among educators as to what constitutes an adequate (or minimal) ETV curriculum.

In Table 11-3, an attempt has been made to provide a summary of the approximate capital costs of delivering an educational TV program via a variety of communications and distribution systems.

The assumptions made in arriving at these estimates are listed below. Program library costs are rather arbitrary, and represent essentially 100% purchases of already available programs. Any significant local preparation of programs may vary this portion of the estimate substantially.

Assumptions upon which Table 11-3 is based include:

(1) A system of 80 schools, 1200 classrooms, 30,000 students centralized within a city rather than geographically dispersed.

(2) Costs include in-school wiring and a TV receiver in each classroom.

	Part of Cost independent of system size (Library plus Head-end or Transmitter)	Part of Cost dependent on system size (TV receivers plus school wiring)	Part of Cost due to rental of cable (Annual Cost X 3) (City wiring)	TOTAL Capital Cost	Cost/Student/ Year
	($000)	($000)	($000)	($000)	($)
VHF/UHF Broadcasting	400	300		700	23.4
ITFS (3 Channel)	440	420		860	29.7
1 Channel on CATV system	70	360		436	14.5
12 Channel private cable system	600	360	375	1335	36.1[1]
IRTV ($10,000/channel originating center) (present)	1480	360	675	2515	69.0[1]
IRTV($3,000/channel originating center) (future)	800	360	675	1835	46
Video playback (VTR in each classroom)	480	670		1150	38.3

[1] Calculated using only a one-year cable rental cost.

Table 11-3

Estimated Capital Costs of Television-Based Educational Systems

(3) For VHF/UHF broadcasting:
  - Acquisition of a small library @ $40,000
  - No allowance for program production costs

(4) For ITFS (2500 MHz)
  - 3 channels, playback only, no live/studio equipment
  - Acquisition of a medium sized library @ $120,000

(5) Single Channel Carried Free on CATV system:
  - Playback equipment plus an ITFS-to-CATV link

(6) 12-channel private cable system:
  - 1 origination center with Videotape equipment
  - Acquisition of a large library @ $480,000

(7) Information Retrieval Television (IRTV)
  - Acquisition of a large library @ $480,000
  - low-cost ($3,000 per channel) VTR assumed available in the future (circa 1975)

(8) Video Playback:
  - Acquisition of a large library @ $480,000

(9) Operating costs not estimated; dependent on use of students, etc.

Since ITFS systems are of special educational interest, Table 11-4 provides a more detailed estimate of the costs associated with an ITFS facility. Here the basic assumptions are:

(1) Costs shown are hardware only, excluding program and operating costs.

(2) A system size of 150 classrooms in 10 different receiving locations, serving a total of 3,750 students is used as the model. Larger systems would permit some reduction in the cost per student per year.

It can be seen that the relatively low hardware cost per student, ranging from $4.34 to $10.27 per year, in most cases

Cost Item	10 Schools, 150 Classrooms, 3,750 Students			
	1 Channel $	2 Channel $	3 Channel $	4 Channel $
Site Survey	500	500	500	500
Studio Equipment				
(a) Monochrome	45,000	45,000	60,000	60,000
(b) Color	90,000	90,000	120,000	120,000
Transmitting Equipment	15,000	27,000	39,000	51,000
Receiving Ant., & Down Converters (9 @ 1,500)	13,500	13,500	13,500	13,500
Distribution System (150 classrooms @ 80)	12,000	12,000	12,000	12,000
TV Receivers & Stands (1 per classroom)				
(a) Monochrome @ 150	22,500	22,500	22,500	22,500
(b) Color @ 400	60,000	60,000	60,000	60,000
Subtotal				
(a) Monochrome	108,500	120,500	147,500	159,500
(b) Color	191,000	203,000	245,000	257,000
Maintenance (10 Yrs. @ 5% of cost per yr)				
(a) Monochrome	54,250	60,250	73,750	79,750
(b) Color	95,500	101,500	122,500	128,500
Total Cost (over 10 yrs.)				
(a) Monochrome	162,750	180,750	221,250	239,250
(b) Color	286,500	304,500	367,500	385,500
Cost per Student per yr.				
(a) Monochrome	4.34	4.83	5.90	6.38
(b) Color	7.64	8.12	9.80	10.27

Table 11-4

ITFS Systems - Cost vs. Coverage
(Note - Hardware Only, Excludes Program and Operating Costs)

may be over-shadowed by the initial and continuing software costs of program preparation.

Table 11-4 also can be used as a first approximation to the costs of a CCTV system. The elimination of transmitters, receiving antennas and down-converters will probably be balanced by the necessity for extra cable and amplifier costs. For a long-haul CCTV system, however, the cable costs will increase proportionately.

One item which is sometimes overlooked is the cost of duplicate copies (prints) of the program material to permit use by different facilities. Table 11-5 provides a rough comparison of various media reproduction costs, for a 1/2-hour program in each case.

Medium	Cost per Duplicate ($) Low Quantity (1-10)	Medium Quantity (10-100)	High Quantity (Above 100)
16 mm Film - Black & White	40	30	25
16 mm Film - Color	100	80	70
1-inch Video Tape	25	25	25
1/2-inch Video Tape	15	15	15
EVR	200	60	20

Table 11-5

Comparative Costs of A/V Reproduction

CHAPTER 11 - BIBLIOGRAPHY

1. "Emerging Technology for Modern Education", Ampex Readout, Vol. 9, No. 2, 1970.

2. Lewis, W.C., "Through Cable to Classroom: A Guide to ITV Distribution Systems", National Education Association, Wash., D.C., 1967 (Library of Congress Card No. 67-30678).

3. McKune, L.E. (ed.), "Compenduim of Televised Education", Michigan State University, Continuing Education Service, Vol. 14, Sept. 1967.

4. Stetten, F.J., "Interactive Television Software for Cable Television Applications", MTP. 354, June 1971, the MITRE Corp., Wash. Operations.

5. Pettit, J.M., and Grace, D.J., "The Stanford Instructional Television Network", IEEE Spectrum, Vol. 7, May 1970.

6. "University Instructional TV Networks - What They Mean to Industry", Session 10 Papers, Western Electronic Show and Convention, 1969

7. Volk, J., "The Reston, Virginia, Test of the MITRE Corporation's "Interactive Television System", MTP. 352, May 1971, The MITRE Corp., Wash. Operations.

CHAPTER 12 - COMPUTER-BASED SYSTEMS

Although the concept of machine-assisted teaching is some 46-50 years old, it is only in the last decade that computers have been applied to education on a systematic basis. Considerable progress has been made, both in the mechanization techniques, and in examining and redefining educational objectives in the light of the computer's capability. As a whole, however, the field is still in the preliminary growth stages and evolving rather more slowly than its advocates have predicted.

In 1960, as an example, when CAI was considered, it meant a student sitting at a Teletype terminal interacting with a computer. Today, more often than not, CAI still means a student sitting at a Teletype interacting with a computer. There have been significant advances, of course, both in hardware and software, but it is a fair statement that computer-based educational applications have not proliferated in comparison with other uses for the computer.

There are a number of reasons for this. The computer, requiring precise, unambiguous instructions, has forced educators to translate teaching techniques which have been largely subjective and unstandardized into more structured form. This may be relatively simple for drill-and-practice instruction, but much more subject to debate for a true dialog system. Thus, the basic step of deciding exactly what the computer is to do, and how it does it, is less clear in education than, for example, accounting or record-keeping.

Computer hardware has improved substantially in this ten-year period. Performance-cost ratios of main-frames and peripheral equipment have risen sharply, and time-sharing and communications techniques have developed from almost academic concepts into primary operating modes of many computer systems.

In spite of this, however, relatively little if any hardware has been developed specifically for educational use since this market is still small. Those prototype systems used for education, some of which are described in this chapter, almost invariably adopted general-purpose commercial computer equipment. This has not proved a barrier to proving feasibility, but it has prevented achieving optimum cost-effectiveness. The lack of a suitable product line of low cost, education-oriented user terminals is a case in point.

Software is probably even more of a barrier to effective educational usage. The interdisciplinary gap between educational procedures and computer mechanization has been bridged only in a preliminary, relatively unsatisfactory way. Some progress toward "natural" programming languages (i.e, those which can be used efficiently by a teacher or student not having computer expertise, yet powerful and flexible enough not to act as a constraint) has been made, but this area remains a long-term bottleneck. As educational requirements become more complex and sophisticated, it may even get worse, particularly for very large, multi-function computer systems.

In spite of these problem areas, the prognosis for growth of computer-based educational applications is excellent, if only because of more critical requirements for improvements in education which simply cannot be met conventionally.

The systems described below offer a good cross-section of progress to date in computer-based education, and provide some indication of trends for the future.

12-1. Stanford University CAI Project

In January, 1963, the Institute for Mathematical Studies in the Social Sciences at Stanford University began a research and development program in CAI, funded initially by the Carnegie Corporation. Subsequently, further financial support came from the National Science Foundation and the U.S. Office of Education.

These grants led to the establishment of a Computer-based Laboratory for Learning and Teaching on the Stanford campus.

This facility has been in operation since December, 1963, serving not only Stanford but other schools both in California and across the country.

The initial CAI system at Stanford consisted of a medium-sized computer (Digital Equipment Corp. PDP-1) and six student stations located within a 100-ft. radius. Each station contained two visual display devices. The first was an IBM-manufactured random-access optical display that presented microfilm source material on a 10" X 13" glass screen. Any microfilm page, or 1/8 page, could be accessed randomly and displayed within one second. This device was subsequently phased out of the system.

The second display, still in use, was a CRT oscilloscope screen capable of presenting a matrix of 1024 X 1024 points of light on its 10" square surface. Since 1024 is equal to 2^{10}, a 10-bit binary code for each of the X and Y axes is sufficient to identify and locate any point on the matrix. Thus the computer can generate any graphical pattern composed of a sequence of matrix dots, under appropriate program command.

In addition, up to 120 alphanumeric/symbolic characters, in 5 different sizes, can be displayed. Vectors also can be presented by identifying the beginning and end points.

A typewriter keyboard is furnished at each station, permitting the student to communicate with the computer.

The first CAI programs, demonstrated in 1963, provided instruction in elementary mathematical logic. In 1964-65, programs in 1st-grade and 4th-grade arithmetic were added. Students utilized these programs both at Stanford and at elementary schools connected to the CAI system by telephone lines, and using Teletype equipment as remote terminals.

During 1965-67, the mathematics and logic programs were expanded, both in scope and in student participation. For example, student enrollment for the drill-and-practice mathematics program increased, by May 1968, to 4353 students in 30 schools throughout California, Iowa, Kentucky and Mississippi.

In 1967, a CAI course in elementary Russian was introduced as a for-credit course at Stanford. The Model 35 Teletype terminals were equipped with Cyrillic keyboards, and audio tapes with earphones were added as the output device. Conventional classroom instruction for this course was completely eliminated.

From 1967-70, both the number of courses and scope of instruction continued to increase. Table 12-1 shows the extent of the CAI curriculum by 1970 and the number of students exposed to each course.

In 1968-69, the system was upgraded by adding a larger PDP-10 computer as the master unit, retaining the PDP-1 as an auxiliary input/output controller. The new system configuration is illustrated in Fig. 12-1. Twelve on-campus display consoles (student stations) are shown, plus a number of remotely-located schools tied into the system through telephone-line communications links.

In May, 1970, a communications satellite was first used to distribute CAI material throughout the Stanford network. This was significant as an indication of the potential for making CAI assessible to isolated areas where terrestrial communications links might be economically unfeasible. The satellite used was NASA'S Applications Technology Satellite ATS-1. Fig. 12-2 illustrates the distribution technique. The CAI program material was transmitted from Stanford to the satellite ground station (a G.E. facility operated by Stanford personnel for this experiment), and then beamed up to the satellite and rebroadcast down to the ground. In this case, the computer-to-student link was through the ATS-1, but the student-to-computer link used the normal inter-school phone lines. In a fully operational system both links would go through the satellite and the phone lines would be deleted or perhaps used only as emergency backup. The experiment did demonstrate, however, the feasibility of this interconnection technique.

Program	66-67	67-68	68-69	69-70
Drill-and-practice mathematics				
Grades 1-8 (block structure)				
California	1,500	1,441	2,475	122
Iowa	-	640	-	-
Kentucky	-	1,632	1,060	-
Mississippi	-	640	2,113	-
Ohio	-	-	101	-
Washington	-	-	92	139
College level				
Tennessee (algebra)	-	-	206	183
Tutorial primary-grade mathematics	53	73	-	-
Tutorial reading, Grade 1	50	88	-	-
Drill-and-practice in initial reading				
Grades 1-3, Remedial 4-6	-	-	442	642
California				
Language Arts	-	-	-	30
Drill-and-practice mathematics				
Grades 1-6 (strands structure)	-	-	-	1,713
California				
Ohio	-	-	-	165
Washington, D.C.	-	-	-	39
Tutorial computer programming	-	-	115	177
Tutorial logic and algebra Grades 4-8	76	197	49	459
Tutorial problem-solving Grades 5,6	-	27	20	18
First-and Second-year Russian	10	30	52	77

TABLE 12-1

Stanford Programs in Computer-assisted Instruction

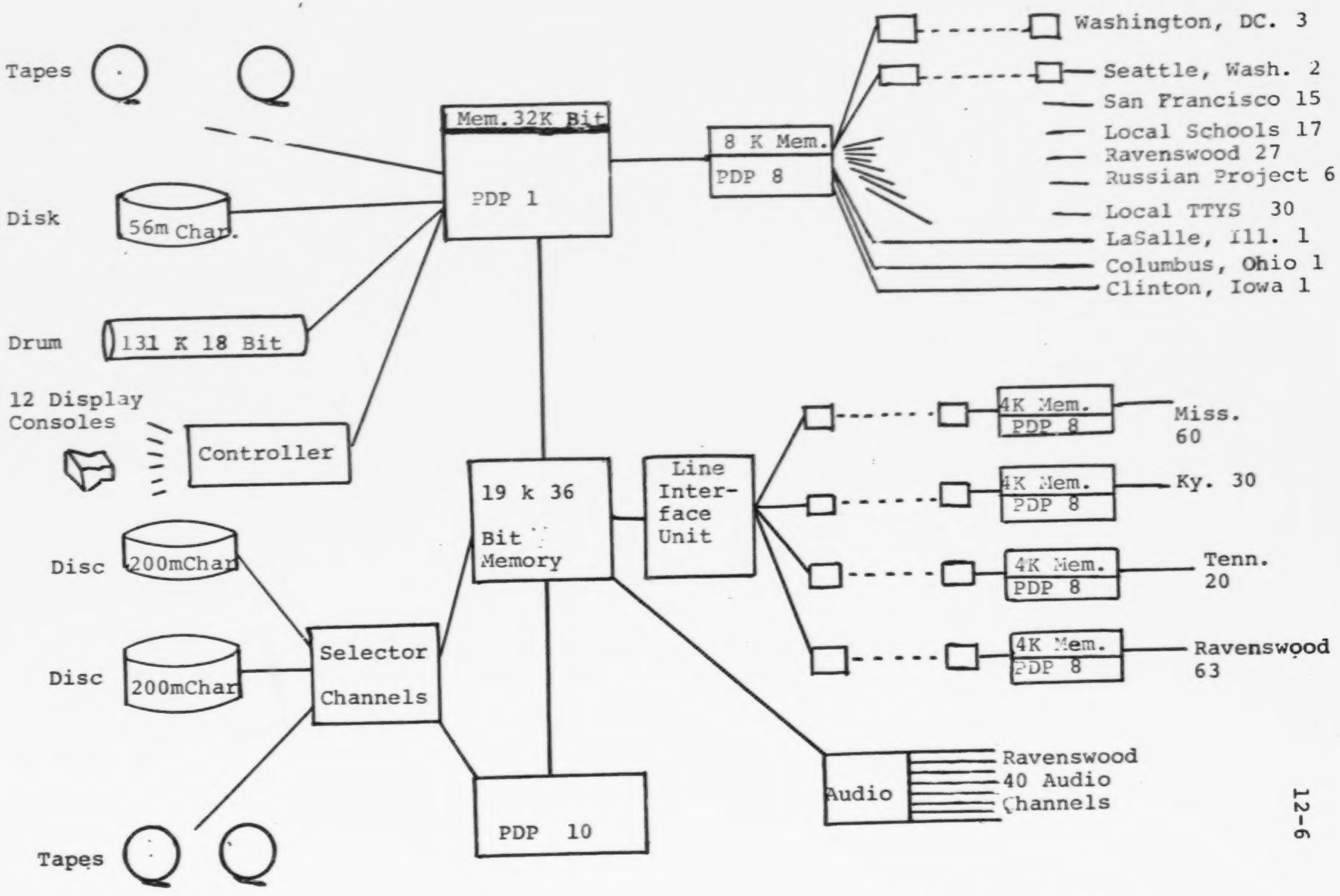

Tapes
Mem.32K Bit
PDP 1
Disk
56m Char.
Drum
131 K 18 Bit
12 Display
Consoles
Controller
8 K Mem.
PDP 8
Washington, DC. 3
Seattle, Wash. 2
San Francisco 15
Local Schools 17
Ravenswood 27
Russian Project 6
Local TTYS 30
LaSalle, Ill. 1
Columbus, Ohio 1
Clinton, Iowa 1
19 k 36
Bit
Memory
Line
Inter-
face
Unit
4K Mem.
PDP 8
Miss.
60
4K Mem.
PDP 8
Ky. 30
4K Mem.
PDP 8
Tenn.
20
4K Mem.
PDP 8
Ravenswood
63
Disc
200mChar
Disc
200mChar
Selector
Channels
PDP 10
Audio
Ravenswood
40 Audio
Channels
Tapes

Figure 12-1 The Stanford CAI System Configuration as of June, 1969.

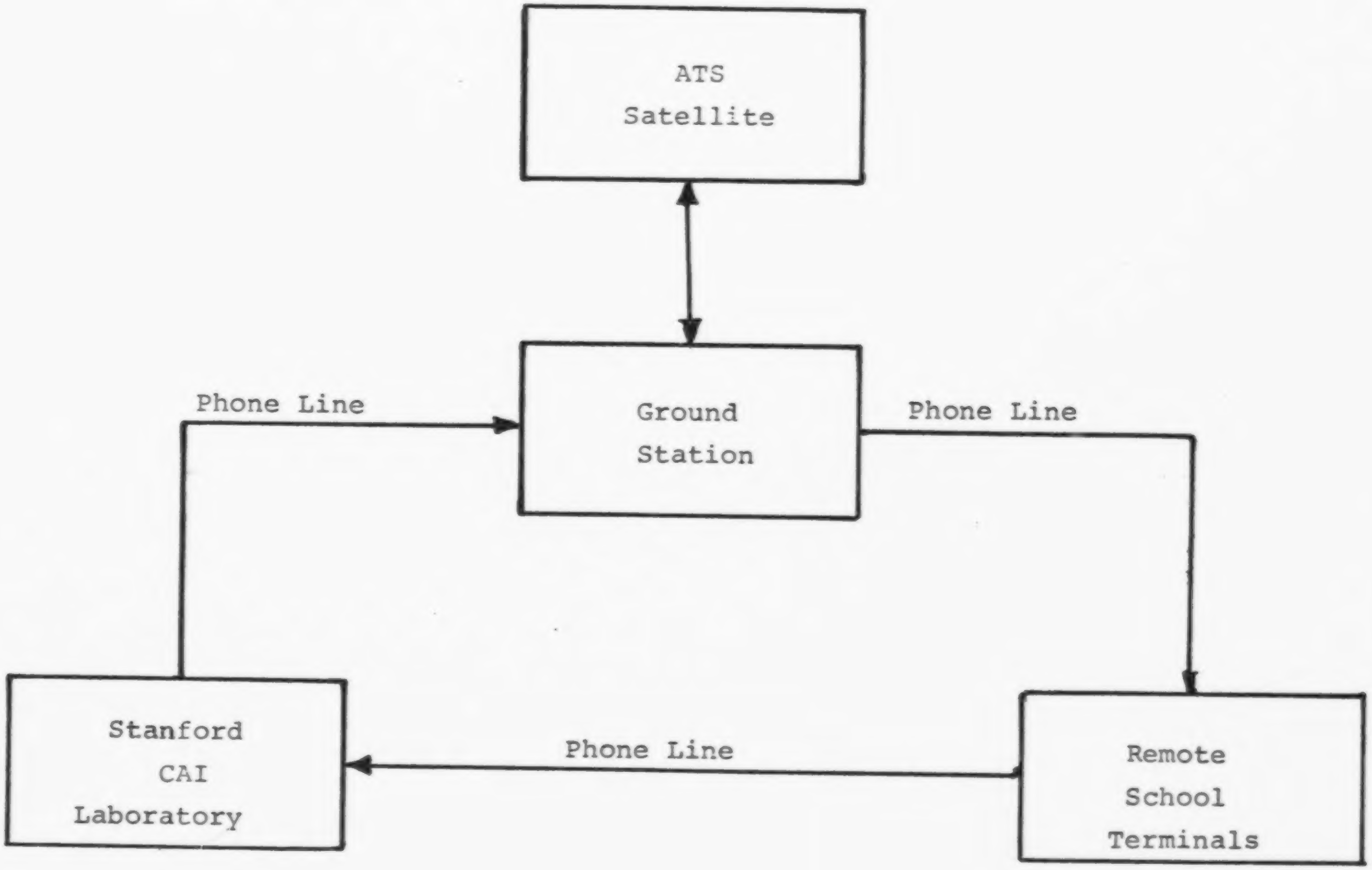

ATS
Satellite
Ground
Station
Phone Line
Phone Line
Stanford
CAI
Laboratory
Phone Line
Remote
School
Terminals

Figure 12-2

Satellite CAI Broadcast

Some attempts have been made to evaluate the CAI programs at Stanford. Pre-tests and post-tests were given to students undergoing the CAI drill-and-practice arthmetic and the Russian language course, and to a "control" group taking the equivalent non-computer classroom courses. The evaluation results, while indicating that CAI students certainly did not test out worse than the control group and in many cases tested better, were still unclear.

Certain conclusions were reached, however. First, it was evident that drill-and-practice CAI, particularly in the lower grade levels, can bring better quality control in instruction, particularly since many teachers find little enthusiasm for the repetitive routines involved. The computer, however, does not become bored and has infinite patience to adjust to the student's rate of learning.

Secondly, CAI may be most attractive in the less affluent school areas since, in general, it is there that teacher preparation and training are least satisfacoty.

Even in the more affluent regions, and in higher education, however, certain courses appear ideal for CAI. The Russian program at Stanford indicated that with CAI the student is free to concentrate more directly to instruction without the distraction of internal adjustment while listening to other student responses. A degree of efficiency is reached that appears difficult to achieve in a classroom, particularly if the class is large.

12-2. University of Illinois PLATO Program

The University of Illinois' program in computer-based education has evolved over a period of more than 10 years. Termed PLATO (Programmed Logic for Automatic Teaching Operations), the initial effort started in 1961 with a single terminal connected to the University's ILLIAC I computer, a medium-speed, 1954-vintage unit.

In 1962-63, the system was expanded to two terminals time-sharing a Control Data Corp. 1604 computer, and in 1964 expanded again to the PLATO III configuration which featured a "computer classroom" of 20 graphic/pictorial terminals connected to the CDC 1604. A network of four associated demonstration centers was added in 1969.

Some of the areas in which computer-based studies have been conducted include electrical engineering, geometry, biology, nursing, library science, pharmacology, chemistry, algebra, computer programming and foreign languages. Techniques have ranged from drill-and-practice to student-directed inquiry.

The components of the present PLATO III system are shown in Fig. 12-3. A student terminal consists of a "keyset"(teleprinter) and a television display monitor. Information presented on the display include fixed photographic information stored on slides and computer-generated or student-generated graphical and/or alphanumeric material. These can be superimposed to provide a composite picture.

The student uses the keyset for entering questions and answers, setting up problems and controlling his rate of progress through programmed instruction. System response is such that the computer answers student requests within one-tenth of a second.

The computer also controls other information devices, such as film projectors. Student terminals can interact with each other, permitting multi-user problem-solving and simulation "games".

The computer keeps detailed records of student progress, and can provide individualized instruction based on past performance of each student. Feedback is provided to "open-ended" questions, reinforcing correct approaches or encouraging a new approach if it is indicated that the student is on the wrong track.

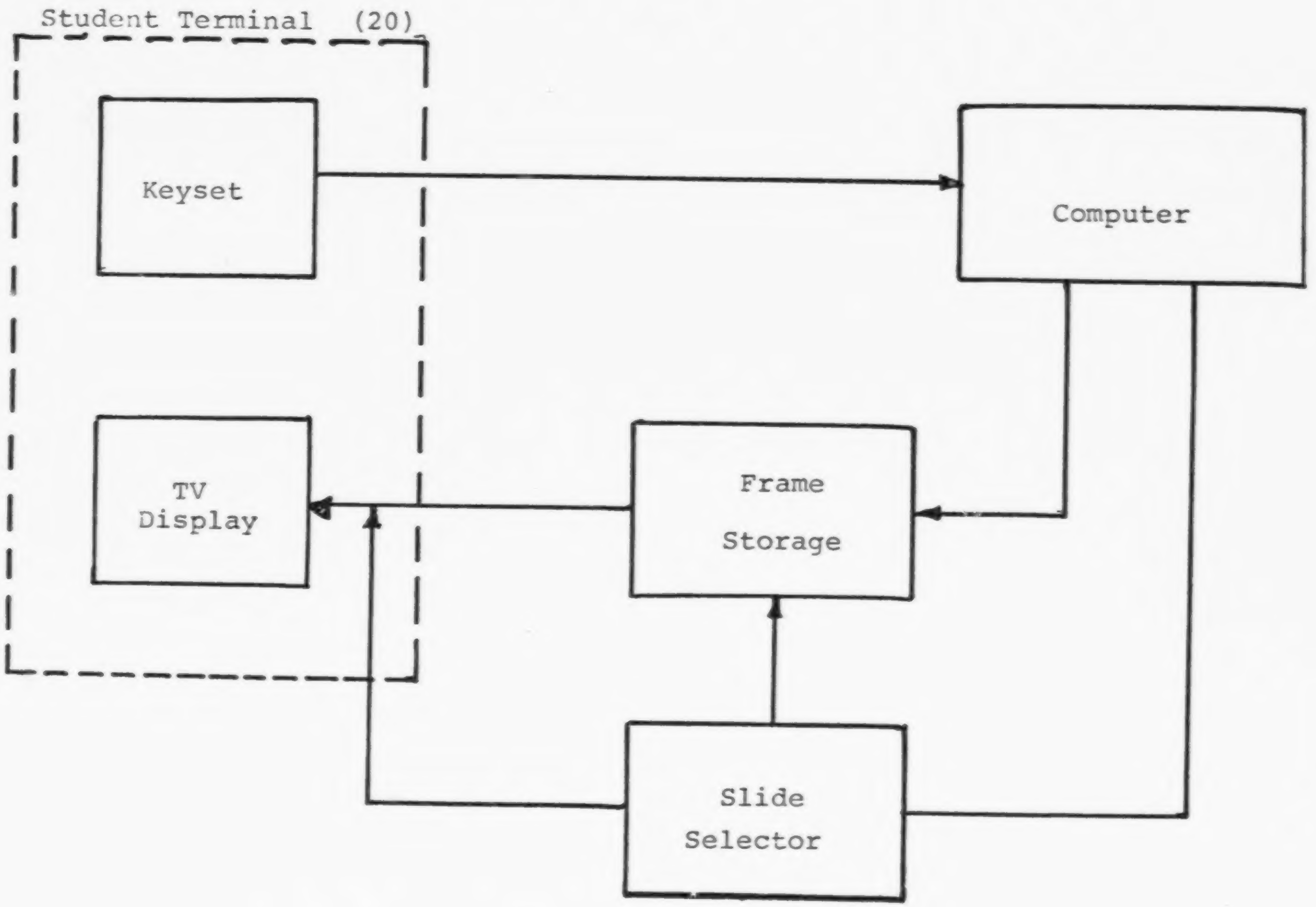

Student Terminal (20)
Keyset
TV Display
Computer
Frame Storage
Slide Selector

Figure 12-3

PLATO Computer-Based System

As an illustration of how the system interacts with the student, one program consisted of 15 geometry lessons, designed to give 7th and 8th grade students an understanding of geometric concepts.

For this program, eight keys on the student keyset are used as controls to draw figures on the display screen. These are shown in Fig. 12-4, with the arrows on the keycaps indicating the direction in which the key will move a spot on a grid displayed on the TV monitor screen. Two other keys are used in conjunction, a "MARK" key which initiates the communication to the computer, and a "CLOSE" key which instructs the computer to close the figure by connecting the selected points.

An example might be the computer asking the student to draw a quadrilateral with a single line of symmetry. Two possible solutions are an isosceles trapezoid and a kite-shape. The student selects the points he wishes to use for the figure. When four points have been selected, the student asks the computer to close the figure and judge it. If it is judged correct, the computer signals "OK" and the student can proceed to the next step of the lesson.

To date, the PLATO systems have involved computer-based education in over 20 fields, with more than 100,000 student-terminal-hours (much of it for academic credit) in course work at all educational levels ranging from elementary grades through graduate work.

Apart from the valuable experience gained in developing instructional strategies and assessing the attitudes of teachers and students, the general conclusions reached appear to be that (1) computer-based education offers valuable advantages in many study areas, and (2) the costs to date have been higher than can be justified for mass acceptance.

PLATO costs have ranged from $2.00-3.00 per student-terminal-hour, which is about in the middle of the range of costs experienced

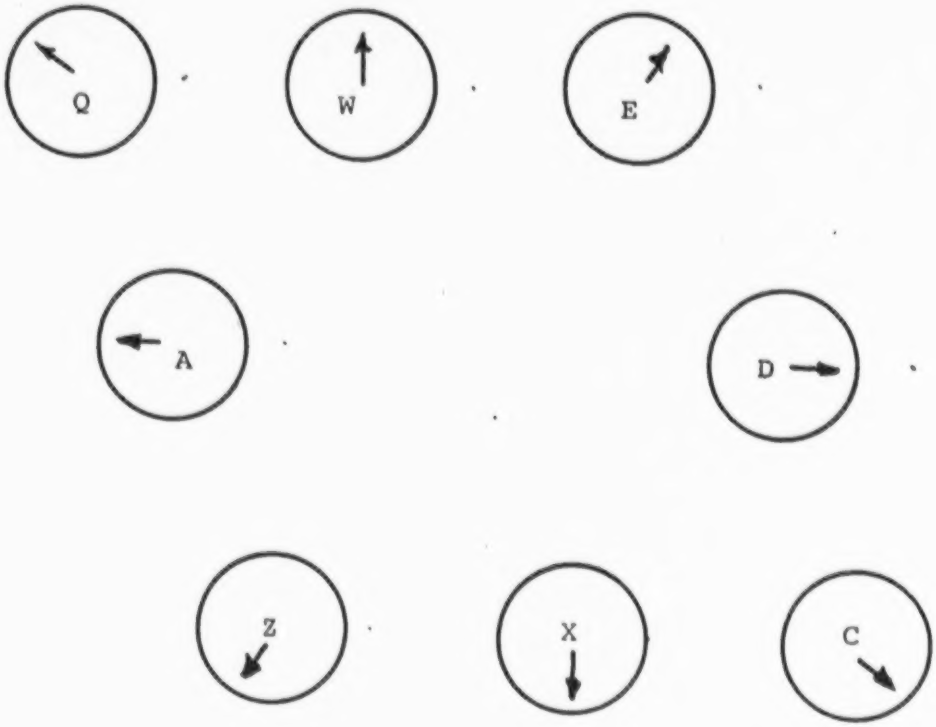


Figure 12-4
Student Terminal Keys Used to Draw Geometric Figures

fo CAI systems in general, estimated at from $1.50-5.00 per student-terminal-hour. This contrasted with about $0.25-0.50 per student hour for conventional instructional costs in elementary schools.

To arrive at a lower cost system more nearly approximating conventional costs, a new conceptual design, PLATO IV, has been proposed. The principal features of PLATO IV are:

(1) The design of a novel student terminal, utilizing a "plasma" display panel.

(2) The use of a large-scale, third-generation computer of the C.D.C. 6000 class, configured to serve up to 4,000 student stations and able to teach several hundred different lessons simultaneously.

(3) Communications capability to within a 150-mile radius of the computer center.

Of these, the key item is the student terminal, designed to combine high performance and low cost. The plasma display panel is a recently developed device which consists of a thin glass panel structure containing a rectangular array of small gas cells (about 40 to the inch). Any cell can be selectively ignited by applying an ionizing voltage to appropriate X-Y grid conductors which run through the cells.

Thus, a point of light can be generated at a selected location by energizing the X-Y grid connectors which intersect at that cell. The result is that a dot display forming any desired graphical image is available. The image itself is similar in appearance to that formed from a dot matrix on a CRT screen, but in this case no CRT is required and there is no deflection of a moving beam of electrons.

The concept can be likened to a display sign made up of thousands of incandescent light bulbs, with images formed by selecting the pattern of bulbs to be turned on.

Apart from the fact that the plasma panel, in volume production, should be simpler and cheaper than equivalent Cathode-Ray tubes, there is another advantage in that the plasma panel is transparent, allowing other optically projected images to be superimposed on the matrix image. Thus any combination of photographic and graphic material can be displayed.

Fig. 12-5 illustrates a proposed student's plasma display terminal. The panel is approximately 12 inches square and contains 512 (2^9 in equivalent binary) digitally addressable positions (cells) along each axis. Thus a matrix of 512 X 512 or 262,144 dots is available for selection and display.

Behind the panel is a slide selector and projection system. Slides are stored on removable microfiche cards, containing 256 microfilm images on each card. The card is mounted on an orthogonal slide mechanism that can move so that any of the 256 microfilm slides can be brought to the projector lens. The image is then projected onto the rear of the plasma panel.

Thus, the total display is the superimposition of the selected microfilm image and the digitally-controllable dot/matrix image. This provides a wide range of visual and graphic capability.

The projected cost of such a student station, in quantity, is estimated at about $1,800, which is about the same as the current cost for a teleprinter alone. If this (or lower) cost can be achieved, then the objective of a low-cost total system may be realizable.

Table 12-2 provides a rough estimate of the cost of a system such as PLATO IV. The main-frame of a computer meeting system requirements is estimated at $2,000,000. Additional memory (2,000,000 words) and input-output equipment are projected at another $2,000,000.

System software costs, including initial course development programming, totals another $1,500,000, and the cost of 4,000 student terminals of the plasma display type is estimated at $7,500,000.

The system usage was assumed at 8 hours per day, 300 days per year. For 4,000 terminals, this is approximately 10,000,000 student-terminal-hours per year. The annual costs were divided by this figure to arrive at cost per student-terminal-hour.

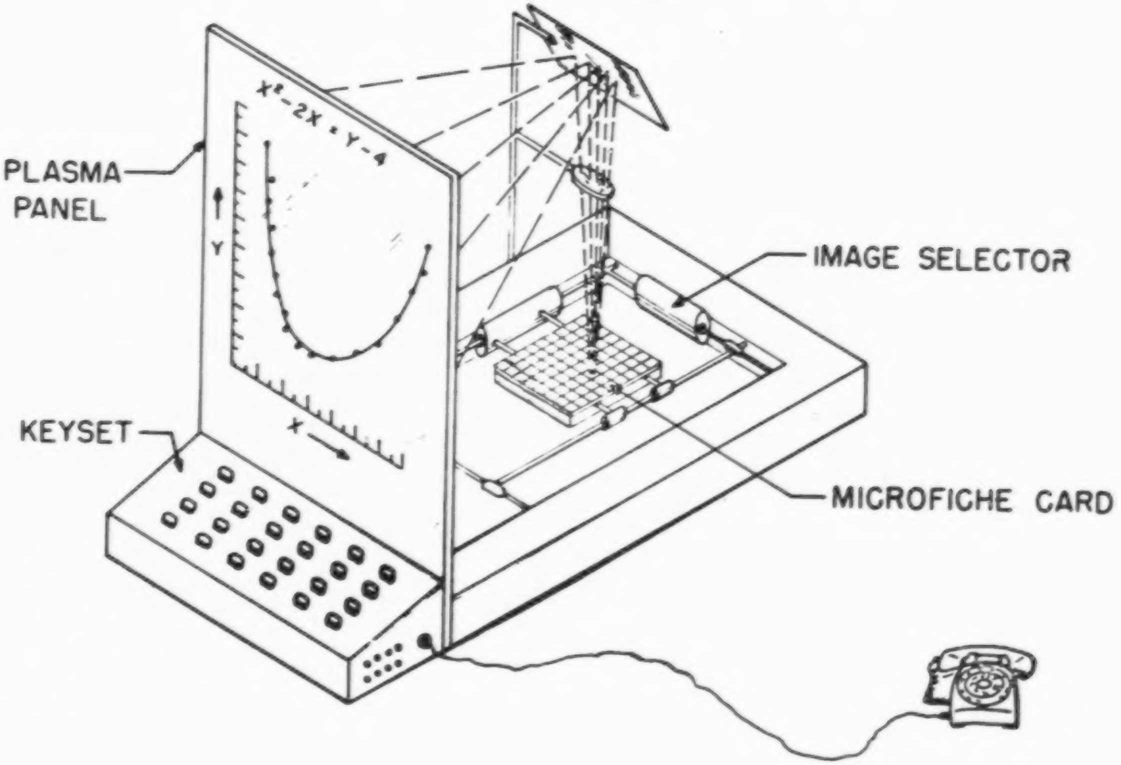

PLASMA PANEL
$X^2-2X=Y-4$
Y
X
KEYSET
IMAGE SELECTOR
MICROFICHE CARD

Figure 12-5

Student's Plasma Display Terminal

Item	Total Cost (Million $)	Cost/Year (5 year period) (Million $)	Cost per Student-Terminal-Hour (Cents)
Computer System (including expanded memory)	4.5	0.9	8
Software	1.5	0.3	4
Student Terminals (4000 @ $1875)	7.5	1.5	15
	13.5	2.7	27
Lesson Material			3
Communications Charges			4
		TOTAL	34¢

TABLE 12-2

Projected Costs, PLATO IV

It can be seen that the total $.34 per student-terminal-hour estimate is in the range of conventional instructional costs for elementary schools. The confidence level in actually achieving these estimates is based primarily on the cost of the terminals ($7,500,000 of a total $13,500,000) and to a lesser extent on the software, since this is less accurately predictable than the computer hardware.

If, however, these estimates are accurate even to within 50%, the economic justification for such a large-scale, centralized facility would appear strong. Implicit in the conclusion is the assumption of adequate communications links, which may or may not be valid.

12-3. Dartmouth Time-Sharing-System (DTSS)

CAI drill-and-practice, tutorial and dialog systems all require that the instructional material be completely programmed into the computer before the student can commence instruction. The problem-solving approach, however, permits the student access to the computer in a less structured mode, in many cases allowing the student to generate his own problems and, in effect, "teach" the computer to solve them.

In the educational field, the Dartmouth College Time-Sharing-System (DTSS) is perhaps the outstanding example of using a large computer on a time-shared basis to provide many remote students with problem-solving capability. Indeed, the developments at Dartmouth contributed greatly to the growth of the commercial time-sharing industry, since General Electric Co. used its cooperative program with Dartmouth in 1963-64 as the springboard for large-scale commercial implementation starting in 1965, and quickly assumed a leading position in this area of computer services.

In 1963, Dartmouth began formulating a system in which learning to use a high-speed computer was considered an essential part of liberal education. (This is not necessarily the same as being instructed by the computer.) To allow a maximum number of students access to the computer at their convenience, a time-sharing system was indicated. Further, a simple programming language was necessary to provent programming from being an operational bottleneck. Convenience and ease in programming is considerably more important in this case, where a wide variety of applications are anticipated, than in a relatively restricted drill-and-practice or tutorial system.

Both of these objectives were met. Through cooperation with General Electric Co., a GE-235 general-purpose medium size computer and a G.E. Datanet-30 communications controller-computer were made available to Dartmouth. Fig. 12-6 shows the original hardware configuration.

In operation, the Datanet-30 serves as the "master" computer, controlling the functions of allocation of storage space, scheduling, and control of the GE-235. The latter processess all data, performs computation and serves as a buffer for transfer of programs. It also carries out peripheral-to-peripheral operations without interfering with time-sharing.

The Datanet-30 scans all user terminals on a clocked basis, at a rate of around 110 times a second. "Jobs" (requests and/or instructions) from any user are run one at a time in the GE-235. If a job exceeds its allotted time, it is temporarily switched to auxiliary storage and later, when its turn reoccurs, is switched back again for further processing. The Datanet-30 periodically queries the GE-235 to see if previous jobs have been completed.

User terminals are standard Teletype units. Originally the system was an "in-house" Dartmouth facility but later, a number of off-campus organizations, including regional secondary schools, were tied in via telephone lines.

Perhaps the key contribution of the Dartmouth project was the development of a simplified programming language which could be learned and used in a matter of hours.

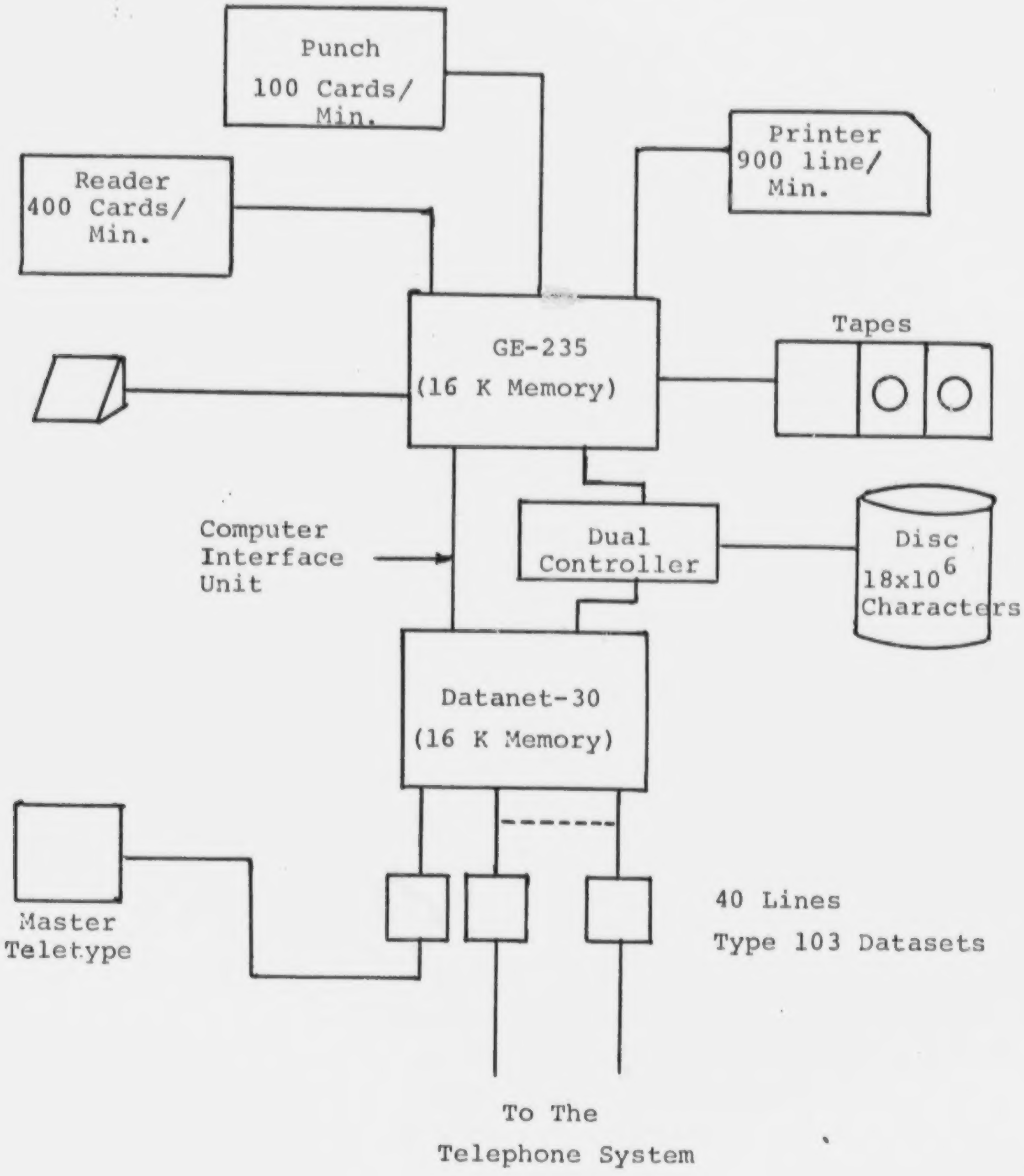

Punch
100 Cards/ Min.
Reader
400 Cards/ Min.
Printer
900 line/ Min.
GE-235
(16 K Memory)
Tapes
Computer Interface Unit
Dual Controller
Disc
18×10^6 Characters
Datanet-30
(16 K Memory)
Master Teletype
40 Lines
Type 103 Datasets
To The Telephone System

Figure 12-6

Block Diagram of Original Dartmouth Time-Sharing System.

Termed BASIC (Beginners' All-purpose Symbolic Instruction Code) and designed originally for students, the language has since been expanded into a more powerful, general-purpose programming language, used in many commercial systems where laymen must communicate with the computer. The beginner, however, may continue to use the elementary portions of BASIC without having to learn the language expansion.

Compared to other programming languages, BASIC is a large step in the direction of "natural language" programming; and has permitted interactive computer usage by many users who otherwise might have been inhibited from "hands-on" operation. Both in its flexibility, however, and its approximation to natural English instructions, BASIC still leaves many features to be desired.

Nevertheless, BASIC permitted widespread usage of the system at Dartmouth by both students and faculty. In most cases, the user, through interactive trial-and-error, developed his own program, debugged it and modified it as required.

This approach, while rewarding user creativity, also served to limit the system capability. All user programs were saved and, as the memory storage space became exhausted, those programs least used were "purged" by being erased. The storage period before purging shrank from an original 3 months to some 48 hours as the library of user programs continued to grow. As a counterploy to protect their programs, users took to the habit of calling up all their otherwise unused programs every day to avoid having them purged. This worsened the program storage situation tremendously.

The situation eventually was eased by the introduction of a new, larger computer system in 1968 (although storage capacity or "parking space" for user-originated programs is still an endemic problem). The new system, illustrated in Fig. 12-7 uses a much larger, more powerful data processor, the GE-635, in conjunction with up to 4 Datanet-30 communications controllers.

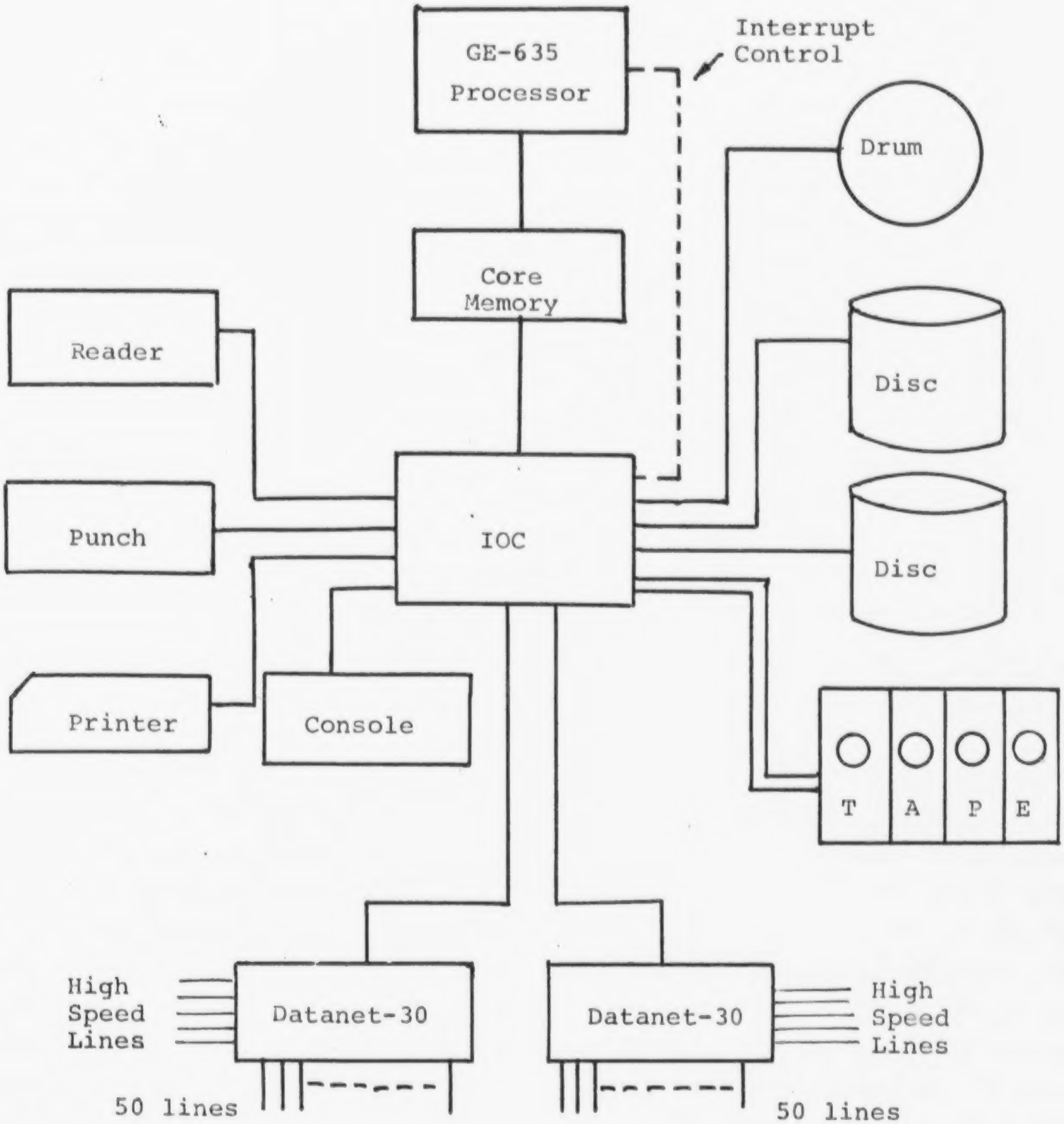

GE-635
Processor
Interrupt
Control
Drum
Core
Memory
Reader
Disc
Punch
IOC
Disc
Printer
Console
T
A
P
E
High
Speed
Lines
Datanet-30
Datanet-30
High
Speed
Lines
50 lines
50 lines

Figure 12-7

Configuration of the present DTSS System

Each Datanet-30 can accept up to 50 separate inputs, so that the system theoretically can service up to 200 simultaneous users. In actuality, however, the increasing sophistication of the users means a bigger average workload per user than on the smaller system. Consequently, the maximum number of simultaneous users is closer to 100, above that number bringing unacceptable delay in execution of requests.

In the new DTSS, the interface to any individual user is exactly the same. Within the system, however, a number of changes have been effected. The Datanet-30's now are concerned only with message switching and communications control. The GE-635 schedules jobs, composes new programs, carries out commands and controls usage in addition to storing user programs. Further, the larger 635 can retain in active core memory the jobs of several users rather than one, so that a number of jobs can be run concurrently.

(As an outgrowth of the work at Dartmouth, the original and expanded DTSS systems became, in effect, the prototypes for the General Electric Mark I and Mark II commercial time-sharing services, respectively. The Mark II, refined and upgraded to network status, is the primary offering of General Electric today).

At Dartmouth, the impact of DTSS upon education may be inferred from the following:

- Some 80% of each Dartmouth class has computer training as a formal academic requirement. About 30 courses in 14 departments use the computer in course work.
- In the area of preprogrammed instruction, Dartmouth has done little, although individual faculty members have programmed CAI courses. In the reverse mode, however, where the student programs the computer to solve his problem (in effect "teaches" the computer), the most experience has been gained, and it is believed this

process is extremely valuable in increasing the logical power of the student.

- The mathematics department has programmed "teaching supplements" in logic, number theory, statistics and linear algebra.
- Engineering students regularly use DTSS in design projects.
- Psychology and social science students have utilized the computer for statistical analysis.
- The business administration school uses DTSS in connection with courses in accounting, finance, production, operations research and investment.

The DTSS also has had some influence upon secondary school education by virtue of its use by a number of schools in the Northeast. From 1964-66, some eight high schools tied into DTSS on an experimental basis. The preliminary results were sufficiently promising to warrant a larger-scale test program. In 1967, with the financial support of the National Science Foundation, a 3-year project exploring the use of computing in secondary school education was initiated. Eighteen schools in 5 New England states, including both public and private schools, participated and were interconnected to the DTSS facility through telephone lines with one or more Model 35 KSR Teletype terminals at each school.

Average costs (9-month year) were about $7,000 per school for a 1-terminal operation, with about 60-65% representing computer time and the remainder telephone line and Teletype rental charges. This approximates the salary of a single teacher.

Average number of users was about 90 per month, or 4 per school day, with an average usage of 1.75 terminal hours/use/month. Thus, on a one usage a month basis, a Teletype terminal might support 3 classes of 30 students each. Usage 3 times a month by individual students would limit availability to the equivalent of a single class.

Some conclusions drawn by the Dartmouth project managers were:

- Teletype and communications time are too expensive to "waste" by using the computer as a teaching machine. The system is best used in creative exploration.
- Programming, at least in BASIC, can be learned in a few hours at the seventh-grade level.
- Even very slow students can productively use the computer.

12-4. IMS Computer-Managed Instruction System

A CMI system, called IMS (Instructional Management System), developed by System Development Corporation, has been operating in various Los Angeles schools.

Students are provided with tests in a format that resembles the usual workbook practice exercise. These tests are presented once or twice a week, with directions prepared on audio tape and available through earphones at a central listening center in the school.

Each test item is keyed to a "teaching objective", and printed on machine-readable forms. When the students have completed the test sheets, they are collected and read into a computer by means of an optical scanner.

The data are analyzed by computer programs that associate student responses with teaching objectives, record individual and group performance, and designate appropriate remedial action, if indicated. A printout of this information is available to the teacher the next morning, describing student learning difficulties, future alternatives and supplementary instructional material. If additional information is required, the teacher can use a teleprinter to query the computer. An on-line query program allows users to formulate queries by responding to a series of multiple-choice options, or by composing a request in a special query language.

The advantage of such a CMI system is basically the major cost reduction, compared to a CAI approach. Large numbers of student terminals are not required, and the computer can operate in a batch processing mode most of the time. Software is also much simpler, since the computer functions are basically record-keeping and comparison.

The disadvantage, of course, is that no instruction per se is given by the computer. As a low-cost management tool, or an interim step before CAI, CMI offers many advantages.

12-5. USC-Operated Information Retrieval System (WESRAC)

Chapter 10 and 11 discussed dial-access retrieval systems in which a student requests an audio or video program from a centralized library, and the program is automatically located and distributed to the requestor. While computers may be used to control accession, they act simply as switching and routing devices, and therefore such systems are "computer-based" only to a very limited and specialized extent.

True computer-based information retrieval and networking systems are those which deal with large"data-bank" management, including file cataloging and storage, updating, access and communications. A large portion, though not necessarily all, of the data-bank is in computer-compatible form (i.e., storable and manipulable as digitally coded electrical signals).

Because the theory of large-file management is still evolving, and acquisition and maintenance of large data-banks are very expensive, educational applications range from the conceptual to the experimental, but have not yet reached operational status. Some semi-educational systems exist, however, which serve industry and educational clients alike. An examination of one of these may be illuminating in terms of techniques which can be utilized for more specialized educational systems in the future.

NASA, stimulated by the staggering amount of aerospace-related data accumulated during the Apollo program, has been one of the leaders in establishing data-bank storage and retrieval systems. A primary information bank is maintained at NASA's Scientific and Technical Information Facility (STIF), College Park, Md. This data-bank is also made available on a decentralized basis to a number of regional centers.

One such center, Western Research Application Center (WESRAC) may be examined as typical. WESRAC, funded by NASA, is operated by the University of Southern California to serve both educational and industry information needs in the Western U.S.

WESRAC maintains computer magnetic tapes, document abstracts, and document reproductions on microfilm, all updated monthly from the central STIF.

Fig. 12-8 is a functional flow chart of the information retrieval system. WESRAC's magnetic tapes contain summaries, called "citations", of over 500,000 items in 34 subject categories ranging from "Aerodynamics" to "Thermodynamics". Tapes contain citations in chronological sequence, and the elements of a citation are composed of accession number, report number, availability, price, title, author, source, and key descriptor words.

Citations are also cross-indexed by key descriptor words (average of 15 per document). The tape file is organized in paired blocks--a coded term block and an information block. The coded term block contains 5-character codes corresponding to descriptor terms on a 1-to-1 basis. The information block contains the stored documentary information.

Retrieval is performed either by specific identification of accession number, title, etc., or if these are not known,

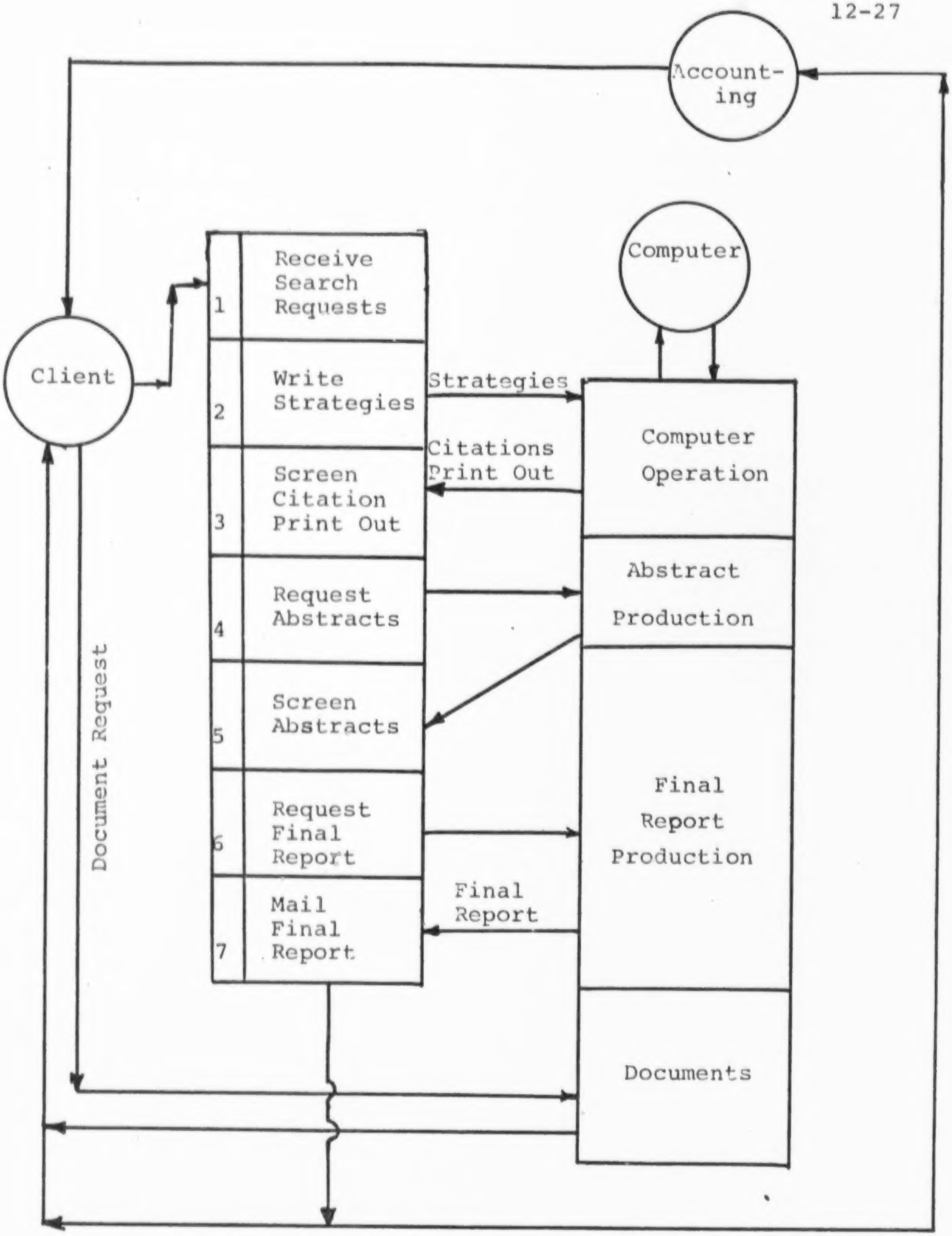

Accounting
Computer
Client
1 Receive Search Requests
2 Write Strategies
3 Screen Citation Print Out
4 Request Abstracts
5 Screen Abstracts
6 Request Final Report
7 Mail Final Report
Strategies
Citations Print Out
Final Report
Computer Operation
Abstract Production
Final Report Production
Documents
Document Request

Figure 12-8

Functional Flow, WESRAC Information Retrieval System by a descriptor matching technique. If, for example, the user wishes all citations relating to a specific technical area, the descriptor terms relating to this area are entered into the system. If the user is not cognizant of the descriptors, the WESRAC specialist in this area performs this function.

The computer search program then compares the entered or "question" descriptor terms (in coded form) against the stored descriptor index. All citations uncovered by the search will be printed out.

The critical area in this procedure is the selection of appropriate descriptor terms. They must be inclusive and broad enough to include recovery of all citations that could be of interest to the user, and yet sufficiently narrow for a feasible computer search, avoiding an output containing an unmanageably large number of citations, most of which have negligible relevance.

At least three basic computer search techniques are currently in use in large retrieval systems. These are termed (1) the linear search, (2) the binary search, and (3) the collating search methods.

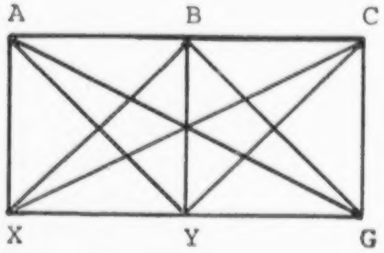
The linear search begins at the first entry in the term table and scans through it, entry by entry, in sequence, until the desired entry is found. It is easy to program but usually requires more search time than other methods. Fig. 12-9(a) illustrates the linear search concept.

The binary search requires that the terms be arranged in some ascending or descending order, as shown in Fig. 12-9(b). The search is based on dividing the table in half, determining which half contains the term, dividing that part again in half, and so on until a match is achieved, alternately decrementing and incrementing the address for the search.

The collating search demands that the question terms and stored "accession" descriptor terms be arranged in some order (collating sequence). The total number of comparisons necessary, as a maximum, is equal to the sum of the question terms and accession terms. Fig. 12-9(c) shows the concept of the collating search technique.

Question Terms = QT

Assession Terms = AT



Total Number of Comparisons (Maximum) = QT x AT

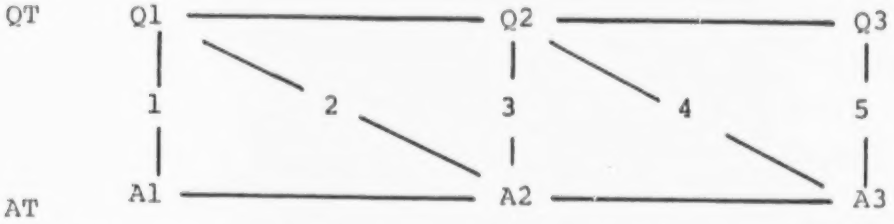
Linear Search Method (a)

Sequence of Comparison	Number of Terms Left in Table
1st	$\frac{N}{2}$
2nd	$\frac{N}{2^2}$
3rd	$\frac{N}{2^3}$
•	•
•	•
•	•
K	$\frac{N}{2^k}$

K = Total Number of Comparisons (Maximum)

$K = AT \times \log_2 QT$

Binary Search Method (b)



Sequences of Comparisons for Collating Search Method (c)

Sorted Question Terms $Q1 < Q2 < Q3$
Sorted Accession Terms $A1 < A2 < A3$

As an example of typical search sequence, comparison will be executed as follows: Q1 compared against A1; if Q1 is greater than A1, AT address is advanced to A2 to compare against Q1; if A2 is greater than Q1, QT address is advanced to Q2 to compare against A2; and so on. Keep modifying the address of QT table and AT table alternately until a match if found. If Q_{last} is less than A_1, the search will be terminated and the system will be set to read the next coded term block.

Figure 12-9

Computer-Retrieval Search Techniques

In most cases, the particular search strategy at WESRAC is determined by a system specialist who is knowledgeable of the WESRAC files and also the field of interest of the individual initiating a request. This strategy is designed to take the given information (which may vary from a specific document accession number to the other extreme of wishing to see "everything" about a very general topic) and instruct the computer in such a way that search time is minimized and yet the requester receives an adequate response.

It is apparent that the skill of this search specialist is a major factor in determining the efficiency of the computer's search, so that systems such as WESRAC are quite removed from being fully automatic. They do represent, however, the current state of operational data-bank systems and can vastly reduce the time necessary to retrieve pertinent information.

12-6. Information Networking Systems

An information networking system, as contrasted to a retrieval system, implies search and retrieval in more than one geographical location, and interchange of information resulting in relatively high traffic flow in any direction. (A typical example would be library-to-library interchange)

The retrieval system, on the other hand, almost always has little data flow from the user to the retrieval facility.

Thus, a computer-based information network is basically a machine-to-machine system, because the high data traffic flow in either direction is generally incompatible with a direct interface to human beings. Information may be stored at the receiving end in temporary buffers, or converted to permanent hard-copy form for later use.

In addition to the machine-to-machine characteristic, an information network implies high speed (broadband) communications and terminal equipment. Further, the large-file management and traffic control software requirements for any retrieval system become geometrically more complex for an information networking system.

For these reasons, computer-based information networking on any sizable scale, remains currently in the experimental/ development stage. Some formidable problems of standardization and compatibility must be overcome before optimum hardware/software configurations can even be defined.

Compatibility problems include:

(a) Standardization of information management and interchange techniques. Some progress, such as standard codes for data transmission (ASCII) has been made, in terms of Federal Information Processing Standards (FIPS). Internal computer procedures, such as file construction, designator terms, file accessing, etc., are completely left to each network's or computer manufacturer's option. Further, no standards on man-machine and man-man interfaces have been attempted.

(b) Machine-machine incompatibility such as differences in
  - Data transmission speeds and costs
  - Input/output equipment
  - Reprography
  - Storage equipment & media (e.g. magnetic tapes, disks, video tapes, etc.)
  - Data handling techniques (e.g. message blocking, headings, I.D. information, error coding and detection, data security, etc.)

(c) Man-machine incompatibility, including:
  - Assessment of user wants and needs (often no correlation)
  - Who requires what type of access? (e.g. to terminals, microform viewers, hard copy, etc.)
  - Human engineering and operating convenience
  - Priorities and scheduling conflicts

- Potential misuse, abuse
- Monitoring of system effectiveness
- Accuracy of descriptor terms and indexing methods (e.g., how should pictures be catalogued?)

Until some common agreement, either through imposed or voluntary standards, addresses at least a substantial portion of these compatibility problems, it is likely that information networking, on any widespread scale at least, will be constrained. When, as an example, it is sometimes difficult to use a tape prepared on one computer or video recorder on another machine of the same make and model, networking of information freely among a wide variety of computer and peripheral equipment appears many years off. Further, it appears likely that the first systems will be business-oriented or sponsored by government requirements, with educational systems some time later.

12-7. Commercial Systems

In parallel with the university-based computer educational systems, some computer manufacturers have developed and offered for sale standardized commercial systesm. Although the market response has not yet been overwhelming, two typical systems are described briefly below to indicate the degree of capability available.

The IBM 1500 Instructional system, introduced in 1966, is designed primarily for use in the drill-and-practice and limited tutorial or inquiry modes of instruction. It uses an IBM 1130 or 1800 computer, together with up to 32 specially designed terminals.

The terminal includes:

(a) A CRT display

(b) A light pen (for student graphical input or response)

(c) A keyboard (for student alphanumeric input or response)

(d) Earphones (in conjunction with an audio play/record system holding up to 2 hours of 5-minute instructional messages)

(e) Image projector (a random-access film strip projector, capable of displaying any of 1,000 stored images on a rear-view screen)

About 15-20 IBM 1500 systems are presently in use at various universities, programmed for a variety of subjects and educational levels. IBM developed a special programming language, COURSEWRITER, for the system and this has in some cases been expanded and improved upon by some of the university users.

In common with other systems, the IBM 1500 stores the students' responses and, on command, can print out a multitude of reports on individual or group performance.

The IBM 1500 is perhaps the most sophisticated of the commercial tutorial-type systems, and can still be considered as subject to future modification and improvement. It can be likened in concept to the Stanford CAI approach, whereas the next system discussed is closer to the DTSS problem-solving mode.

The second commercial system is the Hewlett-Packard Series 2000 Time-Shared "BASIC" System, which has been available for about three years. This is an expandable system, with Models 2000A, 2000B and 2000C progressing in terms of student terminal capacity and computing capability.

The HP 2000A utilizes a standard HP computer (Model 2116) in the upper end of the mini-computer category (16-bit word length, 1.6 microsecond memory cycle time, 16,000 words of magnetic core memory). Added to this are a disc memory unit (350,000 words storage, 16 millisecond word access time) and the user terminals, which are modified Teletype units.

Other peripheral equipment (magnetic tape, paper tape, card readers, printer/plotters, etc.) are available as options.

The HP 2000A can handle up to 16 terminals on a time-shared basis. The 2000B can handle 32 terminals and has expanded memory capacity to store CAI programs. The 2000C also is designed for up to 32 terminals but adds the feature of running batch processing in addition to time-sharing. This permits record-keeping, accounting and administrative functions to be assumed by the computer.

In the time-sharing mode, communication between the terminals and the computer is in BASIC, the language developed at Dartmouth for people unfamiliar with programming. In the non-time-sharing modes, the more sophisticated languages, suchs as FORTRAN and ALGOL, which require programming proficiency, can be used.

The cost of the system ranges from about $90,000 for a HP 2000A with 16 terminals and no added peripherals, to $150-200,000 for a 2000C system with options.

If usage factor of 8 hours per day per terminal is assumed (2000 hours per year), this would be 32,000 hours per year for a 16-terminal system. At a price of $90,000 or over, the cost per student-terminal-hour is about $3.00, not counting sustaining software and operating costs.

12-8. Evaluation of Current Status

A technological assessment of the current status of computer-based educational systems indicates that, even though most computer hardware used to date has been of general-purpose commercial design and not optimized for CAI, there has been relatively little difficulty in technical implementation. The problems encountered (e.g., limited memory storage, marginal and/or expensive communications, unsuitable programming languages, etc.) are more endemic than CAI-related.

Cost-effectiveness is another matter, however, and there is general agreement that the range of $2-5 per student-terminal-hour is certainly too high for elementary and secondary school instruction, and probably marginal-to-high for university-level instruction. Even the estimates of CAI costs, moreover, are in doubt, since most systems use the computer for both educational and non-educational purposes, making the true educational costs difficult to determine.

Even assuming the cost element is known, however, the second half of the figure of merit, the effectiveness, poses further questions. The students, after using the computer, can be tested together with other students but this comparison can be misleading on many counts, however, such as:

- Is the computer being used appropriately, from an educational point of view?
- Are the computer-trained students gaining in such areas as logic, problem definition, problem solving, precision in thinking, motivation, etc., over and above learning the prescribed instructional material?
- Is the computer particularly compatible with the rapid, normal, or slower learner?

This area, which involves setting objectives and measurement criteria on both sides of the man-machine relationship, is still in its infancy in terms of computer-based educational systems. Yet without some formalized, commonly accepted evaluation structure, the "cost-effectiveness" of the system is only a semantic term.

There is therefore, the principal problem of understanding the learning process more precisely, and defining CAI objectives in that context. Secondly, the use of a computer as a "page-turner", while achieving the desired goal of permitting individualized rates of instruction, lacks a good deal in making effective use of the computer's total range of capabilities.

In terms of reducing the cost per student hour, the simplest way is to increase the utilization of terminals, e.g., by running two 8 hour shifts per day on the computer. This might be traumatic to faculty, students and parents alike, but it drastically reduces unit costs without requiring innovation.

A second approach is the use of smaller, "dedicated" computers for in-house CAI systems, so that the substantial cost of leased communications can be eliminated. A number of these smaller systems, capable of handling from 2-32 terminals are now commercially available, ranging in initial price from about $15,000-200,000. Each case must be carefully reviewed on its own merits, however, as the savings in communications costs can easily be outweighed by the inflexibility of the smaller system or by the necessity for specialized programming. The likelihood, however, for lower-cost mini-computer systems in the near future makes the decentralized approach an attractive prospect.

Although it is a fair statement that the growth of computer-based educational systems in the future will depend more upon definition of educational objectives than on technology, there are still technological areas which pose operational problems.

One problem already mentioned, is the lack of a low-cost user's terminal. The ubiquitous and ancient Teletype is utilized because of its comparatively reliable performance at a cost which at least is less than competitive units. In terms of speed, convenience and input-output capability, however, it is far removed from being an ideal interface between man and the computer. More modern terminals offer improved performance but usually at higher cost (particularly when visual display is added) which makes these dubious for the mass educational market. The proposed PLATO IV plasma display terminal appears to have many advantages, but apart from its developmental nature, the estimated cost of about $2,000 still poses a financial barrier to many schools.

It is probable that no single terminal can serve equally well in all computer-based systems. For example, the conventional interactive terminal emphasizes different features from the retrieval system terminal. Nevertheless, a newer, more flexible and lower cost series of user terminals warrants substantial technological effort. The latter, however, is determined by market demand, which in turn may not be impressive without the necessary terminals. This chicken-and-egg syndrome has existed to date and does not appear to be decreasing in the future.

A second major problem, not restricted to educational systems alone, is the cost and adequacy of common-carrier communications. It was noted previously in the DTSS experiment with New England high schools, that about 1/3 of the total operating costs were for communications. If the computer were shared with schools at a greater distance, e.g., nationally, this percentage would increase and at some point be the dominating cost factor.

With a centralized, large-computer concept, there is no way out of this dilemma. Not only must the cost of communications be met, but the adequacy and reliability of the communications links for expanding data traffic applications are currently marginal, and may or may not improve in the future.

Some hope is seen in this respect in the smaller, decentralized systems. Here communications costs can be cut drastically or even eliminated, and the cost of operation per student decreases with increasing utilization. The loss of "economy of scale" advantages inherent in large computers may be more than offset by the reduced communications.

Software, itself, is another problem area. While BASIC represents a step in that direction, the lack of a truly convenient, standardized, "natural" programming language, will continue to inhibit the use of more sophisticated computer systems in education (e.g., dialog or "Socratic" systems). The task of developing such a language appears years away at this point.

Apart from the software necessary for the on-line user, the lack of standardization of software among computer manufacturers and also among computer system users (e.g., with respect to descriptor terms and indexing techniques), poses a formidable barrier to both information retrieval and large-scale networking.

CHAPTER 12 - BIBLIOGRAPHY

1. Alpert, D., and Bitzer, D.L., "Advances in Computer-Based Education", Science, March 20, 1970.

2. Feingold, S.L., "CAI Systems Past, Present and Future", System Development Corp., Paper SP-3492, March 4, 1970.

3. Gordon, R.M., "Computer-Assisted Instruction: Some Operational Aspects", Datamation, Jan. 1969.

4. Hargraves, R.F., and Stephenson, A.G., "Design Considerations for an Educational Time-Sharing System", Vol. 34, Conference Proceedings, AFIPS Spring Joint Computer Conference, 1969.

5. IBM 1500 Instructional System, Introduction to Computer-Assisted Instruction and System Summary, IBM Corp.

6. Jamison, D., Fletcher, J.D., Susses, P. and Althinson, R., "Cost and Performance of Computer-Assisted Instruction for Education of Disadvantaged Children", Research Paper No. 20, July, 1971, Graduate School of Business, Stanford University.

7. Jamison, D., Suppes, P., and Butler, C., "Estimated Costs of Computer Assisted Instruction for Compensatory Education in Urban Areas", Educational Technology, Sept. 1970.

8. Kemeny, J.G. and Kurtz, T.E., "The Dartmouth Time-Sharing Computing System", Final Report, June 1967, Under National Science Foundation Grant NSF-GE-3864.

9. Komoto, D.T., "WESRAC System", Datamation, Aug. 15, 1970.

10. Kurtz, T.E., "The Many Roles of Computing on the Campus", Vol. 34, Conference Proceedings, AFIPS Spring Joint Computer Conference, 1969.

11. Mizenks, A.J. and Evans, A.A., "An Instructional Model for Computer Assisted Instruction", Technical Report 71-2, May 1971, U.S. Army Signal Center and School, Ft. Monmouth, N.J.

12. Nelson, T.H., "No More Teachers' Dirty Looks", Computer Decisions, September 1970, p. 16-23.

13. Pressman, J., "Computer-Assisted Instruction: A Survey", Institute of Electrical and Electronics Engineers Transactions, Vol. E-13, No. 2, Sept. 1970.

14. Suppes, P. and Morningstar, M., "Computer-Assisted Instruction", Science, Oct. 17, 1969.

V. TRENDS AND PROJECTIONS

Chapter 13 Future Applications
Chapter 14 Projected Systems

CHAPTER 13 - FUTURE APPLICATIONS

Since many educational telecommunications systems require a period of years between the conceptual and operational phases, it is useful to evaluate future trends of both the technology and applications of the technology. This chapter focuses on the applications aspect, while chapter 14 attempts to predict some of the most likely system configurations which will evolve in the 1970-80 time frame.

13.1 Predictions for the 1970's Decade

Many predictions have already been made and are available in the literature. One of the most recent (and interesting) is a study conducted by Bell-Canada ("An Exploration of the Future in Educational Technology", 1971). This study used the "Delphi" technique in which a sizeable group of experts were queried as to their projections for the future. The polling took place in successive questionnaires, with the results of previous replies used to refine and modify later rounds of questioning.

The panel of experts were from both Canada and the U.S., although weighted toward the former. As a point of interest, the authors indicate that, for an all-U.S. panel, the estimates of when educational technology will be adopted on a substantial scale would be some 2-5 years sooner, in most cases, than equivalent Canadian views.

Table 13-1 is an over-simplified summary of the study's forecasts. The 20% level indicates the period of early adoption and system refinement corresponding to a point at which approximately 20% of the student population has some contact with the system in question. The 55% level indicates the period of extensive adoption, when a majority of the students have contact with the system.

Educational Level	Information Retrieval and Visual Display Systems	CAI Systems	Data-Bank and Computerized Library Systems
Primary Schools			
20%	1977	1979	1985
55%	1980	1990	1990
Secondary Schools			
20%	1975	1980	1980
55%	1979	1984	1990
Post-Secondary Schools			
20%	1975	1975	1978
55%	1979	1980	1985

Table 13-1

Probable Timing of Adoption of Technological Systems (Bell-Canada Study)

Table 13-1 predicts that automated information retrieval and visual display systems will be the first class of educational telecommunications systems to achieve wide acceptance at all school levels. This is reasonable on two counts. First, the type of instruction received from the retrieved film or video tape is similar to conventional methods and represents less of an educational and psychological departure from the familiar, for both students and faculty. Secondly, the technology, while expensive, is relatively straightforward, involving mainly storage of, and access to, the instructional media. Thus, only hardware design is necessary, and essentially no new software must be developed.

CAI systems, on the other hand, do involve major software effort. As Table 13-1 indicates, they are predicted for adoption at the college /university level first, with a substantial lag before general acceptance at the primary and secondary levels. One reason for this is that the current high cost of CAI, averaging $2-5 per student-terminal-hour, approximates conventional higher education costs much more closely than it does the $.30-.35 per student hour cost at the primary school level. A second reason is the wider availability of computers at the college level, and a third is the fact that undergraduate or graduate students can be used at little or no cost to operate or program the computer system.

In terms of the type of CAI systems anticipated, the study indicates that at the lower educational level, drill-and-practice will receive initial emphasis, with tutorial, simulation and conversational/instructional game techniques lagging by about five years. At the higher educational level, simulation and tutorial, followed by conversational and drill-and-practice, are the expected sequence.

At all levels, the dialog system appears to be the last to become operational, if at all. The software problems, which are related to an imperfect understanding of what a desirable teacher-student dialog should be, present a formidable barrier in the foreseeable future.

It is interesting to compare these CAI forecasts, generated by an interdisciplinary panel, with that of a leading practitioner in the field. Patrick Suppes, who has led the Stanford program for some nine years, predicts that by 1980, 15% of the students in the U.S. at all grade levels will be in daily contact with a computer for some aspect of their instruction.

As an indication of the costs involved, 15% of approximately 1,000,000 elementary-school classrooms is 150,000. Each classroom averages 25-30 students, and for drill-and-practice in mathematics or in reading, one terminal per classroom probably would be adequate. At an estimated cost of $3,000 a terminal, 150,000 terminals would total almost half a billion dollars. In addition, the cost of the central computer systems, the software and the communications links may well bring the total to at least twice that figure, or over a billion dollars, for 15% penetration of primary schools only.

The third category of Table 13-1, that of data-bank and library-oriented information systems, is almost universally agreed to be the farthest away from implementation. As noted in previous chapters, the technology of large data-bank acquisition and management is still in its infancy, a lack of standardization inhibits computer-to-computer information interchange and costs are simply out of reach for most educational users. A stabilizing period of developing and using large data-bank systems for non-educational applications most probably will precede their adoption in education.

13-2 *Changing Role of the Teacher*

If forecasts such as in Table 13-1 are even grossly correct, one key area will be the relationship of the teacher to (a) the technology which becomes more and more a part of the curriculum, and (b) the students impacted by this technology.

Obviously, one hope is that the teacher can be *relieved of much burdensome and uninspiring routine*. Typewriters do not make people into better creative writers, or adding machines make them into better mathematicians. They simply permit mechanization of necessary, but routine, tasks. In the same way, a computer can probably conduct drill-and-practice training better than a teacher, and, further, the teacher would be happy to pass this task on. At this level of sophistication, technology, as a *work-relieving tool*, can be an unqualified success, if *the costs are reasonable*.

At a higher level, the teacher's role in a technologically-oriented teaching environment becomes more complex. Without attempting to *justify* them as *educationally* desirable, certain trends are evident, however.

The Bell-Canada study, for example, envisions that the traditional teacher's role of *leading and directing the class while imparting knowledge* will begin to change around the middle 1970's, into more of a *catalyst to the learning process*. Still later, the teacher is viewed as "*a sympathetic resource utilized at the student's request*".

In this last role, teachers would have at their command a wide range of *mechanized or prepackaged informational resources* (e.g., computer, media library, etc.) and it would become one of their principal functions *to select and direct students to the appropriate resources consistent with their individual educational needs*. As a consequence, the teacher would be, or would have to become, a *resource specialist*, able to *diagnose* student progress and needs, and *prescribe* accordingly.

The more adequate and comprehensive the educational technology, the more routine the teacher can be relieved of, and simultaneously the more he will be free to be the learning director", the prescriber and interpreter of technological learning packages, and the student-technology interface.

A greater proportion of the teacher's time may also be required in the preparation of technological program packages such as instructional audio/visual material, CAI programs, progress evaluation techniques, etc. This area may be the most difficult of all, since it requires much more precise knowledge of the learning process than is currently available. Even after almost ten years of CAI experience at Stanford, for example, the project managers there admit that they are far from being able to develop a "student learning model" which could be used as a base for simulating the cognitive and learning processes of students across even a narrow range of subject areas.

Although this problem may well become the primary responsibility of educational specialists rather than the average teacher, teachers must still adapt the generalized procedures to their individual student needs and responses. They will, therefore, have to have some in-depth familiarity with the way the technology interacts with their students, and how the interaction might produce better results.

13-3 Technology Trends

While the full impact of all the advances in telecommunications technology over the next decade cannot be estimated, a few key trends are highlighted to provide some insight as to the general direction in which educational applications may go:

(a) Electronics hardware costs, particularly when such techniques as Large-Scale Integration of circuits are applicable, will go down relative to software costs. This means that concepts which arose with the beginnings of the computer industry, such as designing general-purpose equipment which could be programmed to do anything, are less valid and will give way to doing as much of the total task in hardware as possible, and minimizing the manpower and costs involved in the software.

Further, the hardware must no longer be procured in large chunks (i.e., as part of a big general-purpose computer) to attain the cost savings, as evidenced by the low prices of mini-computers and even individual logic circuit elements. This means that computing power, or switching capability, or memory storage, or communications control can be decentralized and distributed throughout the telecommunications system.

An example may be illustrative. Sanders Associates has developed a conceptual information processing and distribution system which may hold attractive potential for applications such as CAI. It features the technique of distributed data processing and shared software as follows:

An information data-bank (such as all the pages of a textbook) is stored on a modular disc file, as shown in Figure 13-1. Together with the data are stored software programs which provide instructions as to how to use the data, and identification codes which permit selection of any portion or "page" of the data.

All of the contents of the disc file are continuously transmitted over a broadband coaxial cable, on a party-line basis as described in the section on CATV systems. (The Sanders approach, in fact, is

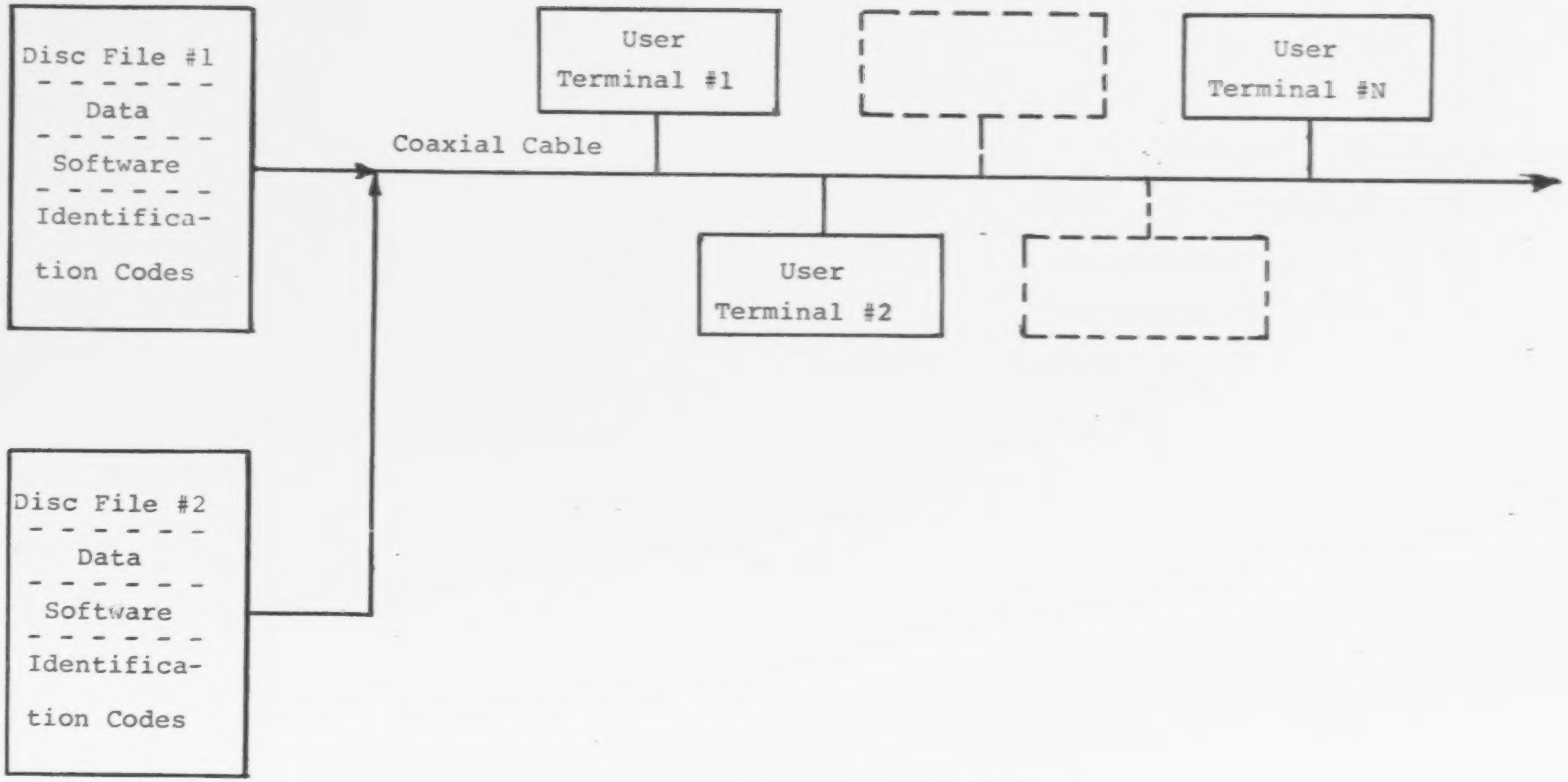

Disc File #1
Data
Software
Identification Codes
Disc File #2
Data
Software
Identification Codes
Coaxial Cable
User Terminal #1
User Terminal #2
User Terminal #N

Figure 13-1

Party-Line, Distributed Data Processing, Information System designed with CATV in mind, as the prime source of broadband channels). The data transmission is in digital form with the identification codes as part of the serial bit stream (which is at a high rate, several million bits per second).

Each user connected into the cable has a programmable terminal, which is essentially a mini-computer with control and display features. The terminal, by using the proper identification codes, can "tune in" or "call up" any portion of the data-bank, which could be pages of text, CAI instructions or any other stored information.

Along with the data, the terminal also calls for and receives the software which tells it how to receive, display and use the data. For instance, a set of microprogrammed instructions could turn the terminal into a drill-and-practice machine.

This concept of "software sharing" where any user does not have to store a large block of software at his terminal, but can "reach out and grab it as it goes by" is very efficient and flexible. It requires "distributed data processing" capability, however, with a portion of the total system"s computational and processing power located at each terminal.

As noted, this becomes most practical when computing hardware costs decrease, or put another way, when each user can have his own mini-computer.

(b) Broadband communications channels to each user will become a necessity, to accommodate the multi-media program packages which educational technology can deliver.

Although some channels can be provided by wireless transmission, the vast majority of systems will require wired links, to bypass the problem of an overcrowded broadcast frequency spectrum. This means coaxial cable distribution systems, on-campus and off-campus as determined by the location of the desired audience. In effect, it is a reconfirmation of the "wired-city" concept.

At present, CATV systems have provided the only substantial start toward the goal of universally-available broadband cable communications. Although established for commercial reasons, they offer to education the prospect of many, in-place, available channels and many more to come in the near future. The use of spare channel capacity for educational telecommunications has already begun, and will inevitably expand in the future. There remain many users not reached by CATV cables, but tying in this group is eminently more manageable than if educators were faced with establishing a completely new, broadband cable network across the entire U.S. In that event, the likelihood would be that no major progress would be made until, perhaps, the time that satellites could broadcast directly to schools and homes.

(c) If cable systems are indeed utilized, the potential educational benefits may become available to a major percentage of U.S. homes and industrial facilities at about the same time as to the schools. Although initial educational telecommunications systems probably will emphasize the on-campus applications, a vast new student audience will be opened up. This will include everyone from pre-kindergarten children to mature adults, with interests and motivations ranging from vocational training to leisure-time hobbies.

This will lead to the situation where the technology of educational telecommunications may be developed and stabilized for the on-campus student segment, and then made available or expanded to the larger home audience. The latter, however, will be much more fragmented and if the goal is education rather than mass entertainment, will require more diversity in programming.

It will then be incumbent on the educational community to demonstrate that such specialized programming can be made both responsive and cost effective.

(d) The availability of broadband communications channels to a sizeable percentage of U.S. students (and later the entire population) will sharpen the need for system definition and planning.

This is true not only in the technical sense, to achieve maximum performance, but most importantly in the educational sense. As an example, suppose that through a combination of cable systems and communications satellite links, it becomes possible to interconnect every school in the U.S. to receive the same program material.

How is such nationally centralized instruction to be evaluated against, perhaps, school-district level centralization? Is the saving in programming cost outweighed by the neglect of specialized community needs?

This leads to the general question of evaluation of an educational telecommunications system which has been mentioned in the introduction to this volume. Standards for evaluation, and a measurement methodology which takes account of both sides of the "man-machine" relation, must be developed as the technology becomes more complex. This evaluation methodology should be established at the time of system planning, rather than after the system is implemented, as one purpose is to guide the direction of implementation.

Some efforts have been made at establishing such an evaluation methodology for large, on-line computer-based systems, although not in the educational field. In an aerospace system, for example, the problem might be to determine system effectiveness on a relatively formalized, retraceable, quantitative basis.

Involved in this determination are equipment-related factors (i.e., performance with respect to specifications, hardware cost) which can be measured precisely. Also involved are factors which may be ambiguous or "semi-precise" (i.e., reliability, maintainability) which can be quantified but only with some lower confidence level. Finally, there is a third set of people-related factors (personnel training requirements, efficiency of software preparation, convenience in using the system, etc.) which have no established measurement criteria, and which can be quantified only with a very low confidence level.

In spite of the variations in meaning and precision, the evaluation techniques which have been utilized do attempt to include and treat all of the above categories. Initial results are often suspect, but repeated iterations tend to produce more generally accepted evaluations.

Educational telecommunications systems are in the same category. An evaluation of the effectiveness of a CAI or an ITV system must include measures of educational performance as well as equipment performance to have any substantive meaning.

The task of developing and utilizing such evaluation methodology for educational systems remains yet to be undertaken, but it is a crucial one in terms of best utilizing the available technology.

A simple example may be pertinent. Assume an ITFS system with one-way capability to transmit instructional TV programs to 500 off-campus students would cost $500,000. The capability to permit student questioning and "answer-back" would cost an added $250,000. How can it be determined that this increased capability is, indeed, worth $250,000? Or, perhaps, that it is not worth $250,000 but is worth $150,000?

Obviously, only an evaluation system which can blend educational value with technological cost-effectiveness can provide an answer. It is probable that the decision-maker in this case might intuitively attempt such a correlation, but this seat-of-the-pants technique leaves much to be desired.

The technological trend to more complex systems ideally, then, should be accompanied by a trend to more objective system planning and evaluation. This would require, perhaps, a new breed of interdisciplinary educational technology specialists.

CHAPTER 13 - BIBLIOGRAPHY

1. "Communications Technology for Urban Improvement", Committee on Telecommunications, National Academy of Engineering, Report to Dept. H.U.D., Contract No. H.1221, June, 1971.

2. Doyle, F.J., and Goodwill, D.Z., "An Exploration of the Future in Educational Technology", Bell Canada, Jan. 1971.

3. Smythe, R.E., "Economically Viable CAI", Sanders Data Systems, May 1970.

4. Suppes, P. "Computer-Assisted Instruction at Stanford", Technical Report No. 174, May 19, 1971, Institute for Mathematical Studies in the Social Sciences, Stanford University.

CHAPTER 14 - PROJECTED SYSTEMS

In any attempt to project educational technology into the future, and to determine *which system configurations are most likely to emerge* during the 1970-1980 decade, the critical stumbling-block remains as stated in the introductory pages of this volume, i.e., *definition of educational objectives*. Again, these are the responsibility of the educational community and the public, and outside the scope of this chapter.

The technology *does have a substantial inertia of its own*, however, in terms of cost and performance trends. From these trends, projections can be drawn as to the *logical evolution of educational telecommunications systems*. Such an evolution is described below, with the implicit presumption that educational objectives *will not become so restrictive* as to eliminate the need for telecommunications-assisted instruction of the type illustrated in Chapters 10-12.

14-1 Concept of the Educational "Telecenter"

Either the *dial-access retrieval system* or the *computer-based instructional system which serves many students* requires an expensive, electronically sophisticated *central facility* which stores program material and responds to student requests.

As more programs are developed, it is likely that the *cost* of constructing and maintaining such a central facility will be more than a single using institution can bear, in much the same way that a library is too expensive for only one user.

Because of this, it is likely that the "educational telecenter" concept will become more prevalent. The telecenter would be a centralized storage, distribution and service facility for a hierarchy of many users.

The concept, of course, is not unique and is based on the economies of scale that any large centralized facility can achieve. The Dartmouth-Time-Sharing-System, for example, uses its large computer to serve many off-campus users.

To date, however, such facilities have been single-functioned (e.g., dial-access or CAI but not both). In the future it is likely that they will be multi-functional and planned for specific community or regional entities.

Figure 14-1 illustrates the components of such a telecenter. There would be a multi-media repository of educational software, including films, filmstrip, slides, video and audio tape, and documents (which could be either in original or condensed microfilm form). There also would be studio production facilities to broadcast live programs or to record material on any medium for later playback.

The telecenter would have low-cost reproduction facilities, so that duplicate film prints or tapes could be prepared and delivered to users who are not tied into the distribution network.

Up to this point, the telecenter functions essentially as a random-access retrieval system. Integrated with this function, however, there would also be a computer-based instructional and information system.

The time-shared computer would be capable of acting in any instructional or interactive mode, and would also keep records of student progress for CMI purposes. In addition, the computer would provide access to a number of data-banks, each being a library (in computer-compatible form) of information about a specialized subject.

For example, the data-banks could be on individual magnetic discs, with one containing historical data for history students, a second containing the equivalent of a Russian or French dictionary for foreign-language students, etc.

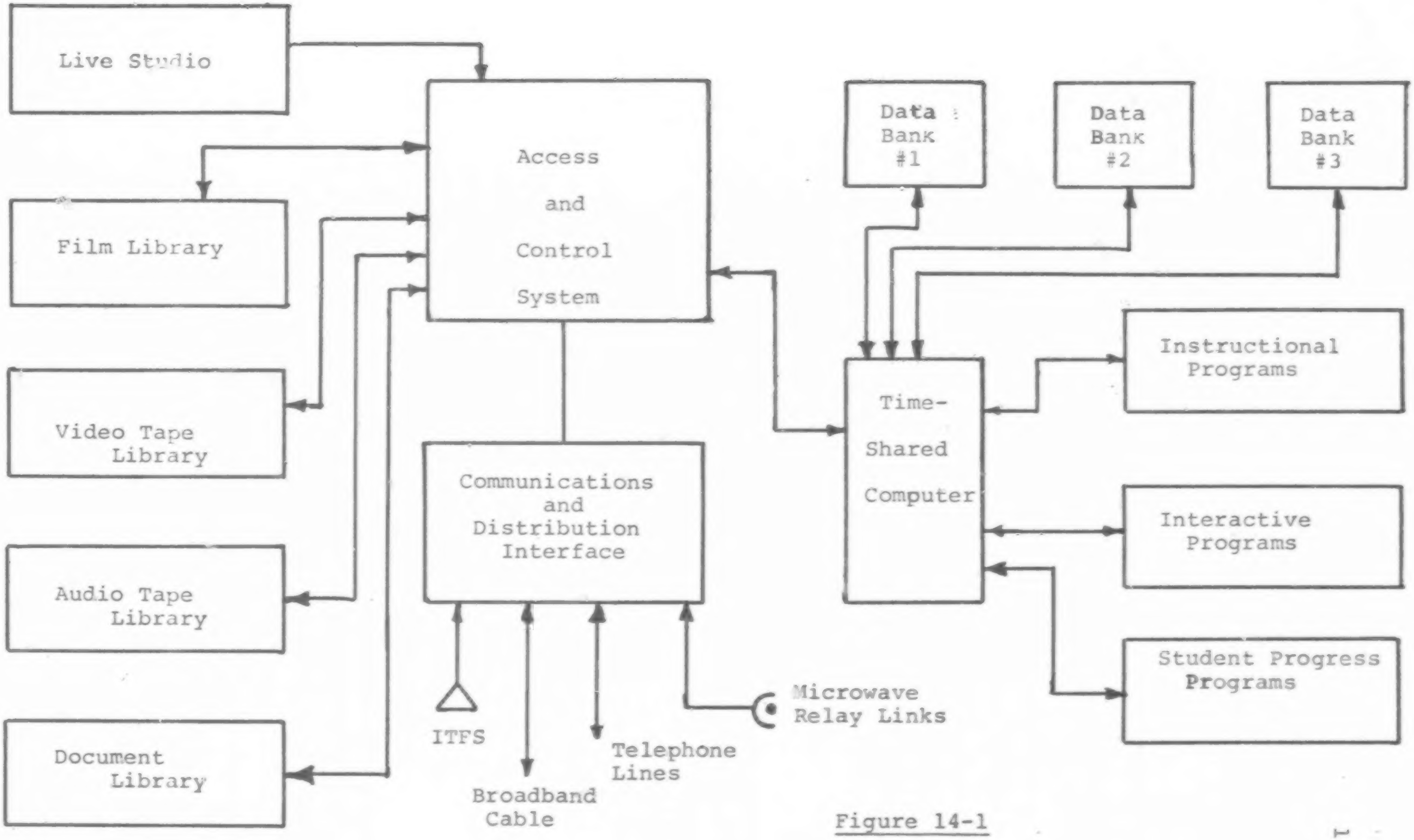

Live Studio
Film Library
Video Tape Library
Audio Tape Library
Document Library
Access and Control System
Communications and Distribution Interface
ITFS
Broadband Cable
Telephone Lines
Microwave Relay Links
Time-Shared Computer
Data Bank #1
Data Bank #2
Data Bank #3
Instructional Programs
Interactive Programs
Student Progress Programs

Figure 14-1

Educational Telecenter

Each data-bank would contain its own "index" and modular software so that it could provide instructions to students on how it should be used.

The computer would also serve as the master system controller, providing access to any requested information and directing traffic. For complex telecenters, mini-computers, under the control of a master computer, might be used to share in any of these functions.

The telecenter's communications interface would be capable of matching any commonly-used mode of transmission, using broadband cable or wireless for most outgoing messages, and narrow-band for selected incoming messages where the amount of data involved is small.

All in all, the educational telecenter would function in the same way a modern hospital or medical center does. The expensive X-ray, open-heart surgery, intensive care, etc. equipment which such a hospital maintains are beyond the financial capability of a doctor's office, and in most cases would not be used often enough at the local level to justify their purchase even if funds were available.

Just as a hospital in no way obviates the necessity for the doctor's office, however, the telecenter will not eliminate local instructional technology but supplement it.

Thus, concurrent with the growth in centralized facilities, there may well be a parallel growth in decentralized, special-purpose educational systems. Small, time-shared CAI systems, for example, appear very attractive for limited instructional objectives. The cost and manpower of large data-banks and multi-media libraries, however, would force centralization of the more ambitious systems.

The hierarchal level at which telecenters should be established is a subject for much future study, and will involve educational jurisdiction as well as technological and financial considerations. Whether, for example, a telecenter would be justified for each school district (some 20,000 odd in the U.S.) cannot immediately be determined, but it may be a logical starting point for feasibility studies. For higher education, it would appear that only the very large universities and colleges would be able to entertain the idea of a telecenter, at least for some years to come. The smaller colleges, however, might find that a regional telecenter, serving some number of colleges, would be justifiable on a cost-shared basis.

14-2 Evolving Telecommunications Networks

The concept of the educational telecenters, if implemented, must be supported by an appropriate communications and distribution network.

A prime requirement of such a network is that it provide broadband capability to each user. Since many of the programs will be television-like in nature, the equivalent of at least one 6 MHz TV channel must be made available to all user locations. In most cases, several channels rather than one will be required.

It is very doubtful that such broadband coverage can be achieved through wireless broadcast techniques. The shortage of frequency spectrum and the competition for those few broadcast channels still available makes a significant expansion in this area unlikely.

The alternative is distribution by coaxial cable to the end-user, and this does appear very promising. It has been pointed out that CATV systems are already meeting some of the requirements in this regard:

(a) CATV systems usually have spare channel capacity. The newer, larger systems will be required to have this capacity and to make a substantial proportion of it available for education.

(b) CATV systems usually provide free connections to schools within their area of operations, so that regardless of the number of homes wired up, each school can receive all channels of the system.

(c) Future systems will be required to have two-way communications capability.

For a school district to take advantage of CATV cable communications, however, the following questions must be addressed:

(a) Most CATV systems can transmit only from their "head-end" studio, or from signals brought into that point. Thus, a school district must either originate programs at the CATV system studio, or provide a connecting link from its own origination facilities.

(b) The CATV systems in any area may not provide coverage to all schools (or homes), since municipal and school district jurisdictions are not identical. Some means must be provided to "plug the gaps" in coverage.

(c) The responsibility for user terminals must be determined. If interactive communications are desired, special terminals must be provided at each user location. Schools may furnish their own, but home terminals may provide a problem in terms of cost and operation/maintenance responsibility.

The configuration of Figure 14-2 appears to be a logical first step in addressing these factors, and also a natural incremental evolution from the CATV network which will be installed in any event in many U.S. communities.

It is assumed in Figure 14-2 that a school district will be the educational entity which will coordinate an overall

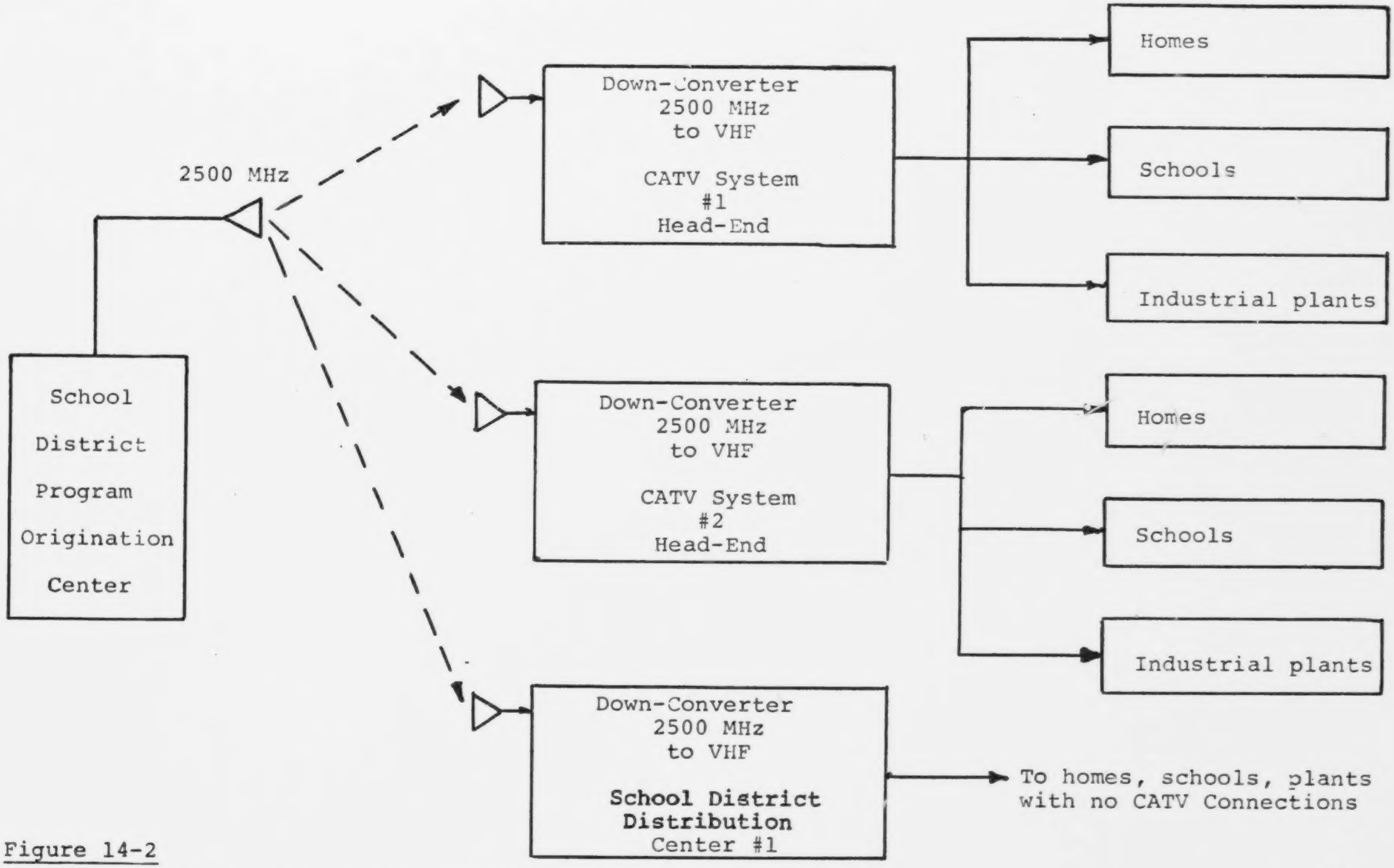

School
District
Program
Origination
Center
2500 MHz
Down-Converter
2500 MHz
to VHF
CATV System
#1
Head-End
Down-Converter
2500 MHz
to VHF
CATV System
#2
Head-End
Down-Converter
2500 MHz
to VHF
School District
Distribution
Center #1
Homes
Schools
Industrial plants
Homes
Schools
Industrial plants
To homes, schools, plants
with no CATV Connections

Figure 14-2

Projected Community-Level Educational Network (1973-74) telecommunications plan. The "program origination center" of Figure 14-2 would, in its simplest form, merely be a TV broadcast studio, similar in capability to the CATV studio but located at a more convenient site for the educational community. Its sole product would be educational or instructional TV programs, and only one-way communications capability would be involved.

In its most sophisticated form, the program origination center would become the telecenter of Figure 14-1, offering a variety of interactive educational services. Since this would require special user terminals and complex switching and control circuitry in the CATV network, the full two-way system appears many years off.

As shown in Figure 14-2, communications from the school district program center would be by ITFS broadcast to each CATV system head-end within that district. Common-carrier cable or microwave links, or privately-owned cable are alternate possibilities, but in most cases ITFS would appear to be a superior choice for two reasons:

(a) Only a small number of receiving points are involved.

(b) The ITFS signal could be beamed to antennas located most favorably for reception.

At each CATV reception point, there would be a receiving antenna and a "down-converter" which translates the 2500 MHz ITFS frequency down to a standard TV channel so that a TV receiver can accept the signal.

The question of who would pay for the cost of this antenna and down-converter is undecided, but it is a relatively small one-time capital expenditure. Other than that, the CATV system operator incurs no operating and maintenance costs above those which would normally be required for his commercial subscriber activities.

Since the CATV systems may not reach all target schools, it may be necessary to supplement the CATV cable network with school-owned distribution systems. Figure 14-2 shows one such distribution center, which would be very similar to a CATV head-end except that it would be equipped to receive only the ITFS broadcast, and distribute it to those users not part of a CATV system. As many centers as necessary would be set up to provide 100% coverage.

The result would be a hybrid broadband telecommunications network available for one-way educational transmission, and achieving eventually 100% coverage within a specific localized area.

For those communities which have operating CATV systems already covering a major portion of the population, the incremental cost of a system such as shown in Figure 14-2 would be relatively small. Of more critical impact would be segmenting the target audience, and preparing or acquiring the program library. If it is assumed that these tasks can be performed satisfactorily, there is no technological reason why many communities could not have an operational facility, such as in Figure 14-2, by 1973-74. The availability of ITFS channel frequencies may be a problem, but it is likely that more would be available with a planned, centralized approach than by individual educational institutions in the same geographical area competing for the same spectrum.

At a higher level of aggregation, it may be more efficient to prepare, store and distribute program material from a regional center, embracing a number of school districts. Such a configuration is shown in Figure 14-3.

Because of the longer distances involved, it is probable that low-power ITFS broadcasting would be inadequate in this case. Again, common-carrier microwave or cable links could be used from the regional program center, but a more cost-effective solution appears to be use of channels on a domestic communications satellite to relay the signals to local school districts.

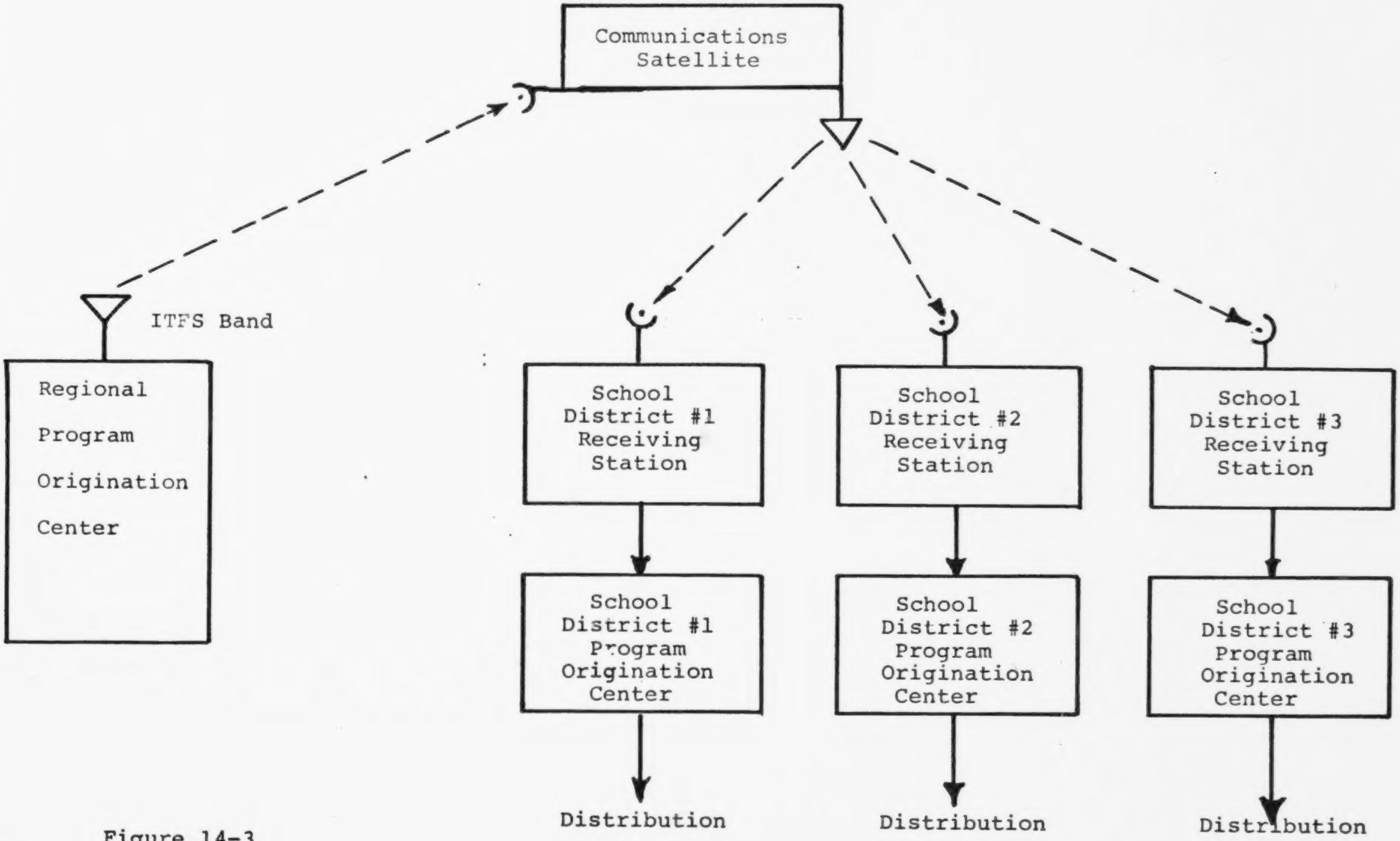

Communications Satellite
ITFS Band
Regional Program Origination Center
School District #1 Receiving Station
School District #2 Receiving Station
School District #3 Receiving Station
School District #1 Program Origination Center
School District #2 Program Origination Center
School District #3 Program Origination Center
Distribution
Distribution
Distribution

Figure 14-3

Projected Regional-Level Educational Network (1975-77)

Since 2500 MHz is also reserved for educational use in satellite communications, the same frequency band can be used in this case as in Figure 14-2.

The regional program origination center would broadcast the program material up to the satellite, from which it would be retransmitted down to all school districts in that region. Each school district receiving station would have a special receiving antenna designed for use with the satellite. From the reception point, the signal could either be down-converted to standard VHF/UHF TV frequencies, or rebroadcast at ITFS frequencies over a local network as in Figure 14-2.

Implementation of such a regional network must await the arrival of an operational domestic satellite, with 2500 MHz educational channels and sufficient broadcast power to be received by relatively inexpensive community-level ground stations. The earliest estimate for this is about 1974-75, assuming no further FCC delay in authorizing domestic satellites. Consequently, the network of Figure 14-3 does not appear likely before 1975-77. It is possible, of course, that terrestrial communications links might be used, but current costs are high and not expected to decrease significantly.

A still higher aggregation level would be a national educational telecommunications network, and a possible configuration for this is illustrated in Figure 14-4.

Here, educational programs would originate from a national center (or possibly one center for each time zone). The signals would be broadcast, again at ITFS frequencies to any (or all) of a variety of satellites. One would be a regional relay, distributing the signals to regional centers, each similar to Figure 14-3. Another would distribute the programs to community or school-district receiving stations, and would require higher transmitting power to reach the more widely dispersed, less expensive ground stations.

The most advanced satellite would be a "direct broadcast" type with sufficient area coverage and radiated power to be

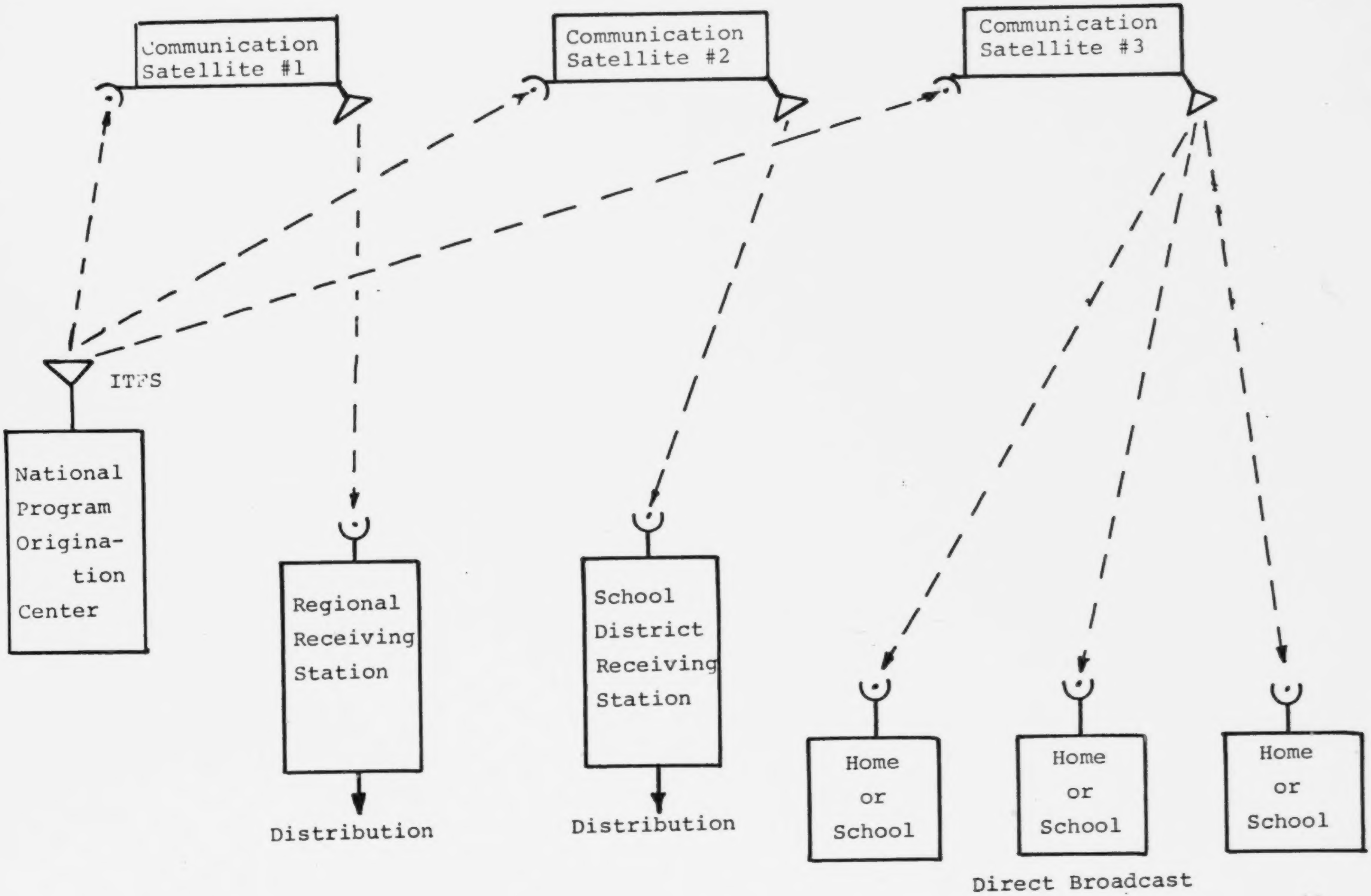

Communication Satellite #1
Communication Satellite #2
Communication Satellite #3
ITFS
National Program Origination Center
Regional Receiving Station
Distribution
School District Receiving Station
Distribution
Home or School
Home or School
Home or School
Direct Broadcast

Figure 14-4

Projected National Educational Network (1978-80) received on home TV receivers, perhaps fitted with special (but low-cost) directional receiving antennas. The achievement of such high power levels appears some 5-10 years away, so that this portion of the national network could not be implemented before 1978-80.

The systems of Figures 14-2, 14-3, and 14-4 would be both evolutionary and mutually supportive. It appears reasonable that the localized approach, being simpler and less costly, would be tested thoroughly before proceeding to a higher aggregation level. Software and program material could be used at any level, if appropriate interface standards are established.

14-3 Interactive Systems

Figures 14-2, 14-3, and 14-4 have been shown as one-way transmission networks, essentially broadcasting educational TV to an audience already equipped with standard TV receivers. These are far from being the ultimate educational telecommunications facilities (possessing not even minimal flexibility) but simply the easiest and most inexpensive to achieve, if 100% coverage and TV-type instruction are the key considerations.

If interactive education is an objective, and this is certainly mandatory for computer-based instruction or even dial-access retrieval, then the user terminal can no longer be a passive TV receiver and, further, the system must provide two-way communications. These requirements substantially increase the cost and complexity of any projected network.

Perhaps the largest total cost is the user terminal, since the quantities will be high. For this reason, such low-cost devices as the Touch-Tone telephone terminal have been utilized, but this is an input device only, and severely limited to a small number of alphanumeric code possibilities.

Similarly, the inadequacies of the Teletype terminal have been noted, with the proposed Plato IV plasma display, for example, considered as an alternative. Even this approach, however, has the disadvantage that no computation capability is available at the terminal.

With the marginal adequacy in communications links, the software problem of large centralized computers, and the drastic reduction in cost of small data processors such as mini-computers, it appears logical to distribute some of the total system computing and memory capacity at the users' location.

Consequently, a projected general-purpose, interactive, user's terminal might be the configuration of Figure 14-5. Here a mini-computer with expandable modular memory is an inherent part of the terminal

A digital tape cassette unit would also be included. The interchangeable cassettes would contain software instructions to the mini-computer for any desired application, and also any local data-bank required by the user.

A display section would include the standard TV receiver, but also the capability to act as an interactive CRT alpha-numeric/graphical terminal. Queries, instructions and responses would be entered in the keyboard.

The communications interface would be compatible with the broadband cable input and with any narrow-band reverse communications link which might be used.

It is estimated by terminal manufacturer's that the user's terminal of Figure 14-5, if standardized and produced in high volume (hundreds of thousands of units) could be sold at about $1,500-2,000 with today's technology, and perhaps below $1,000 in five years. While this is not yet low-cost, it is certainly competitive with currently used terminals without storage and computational capability.

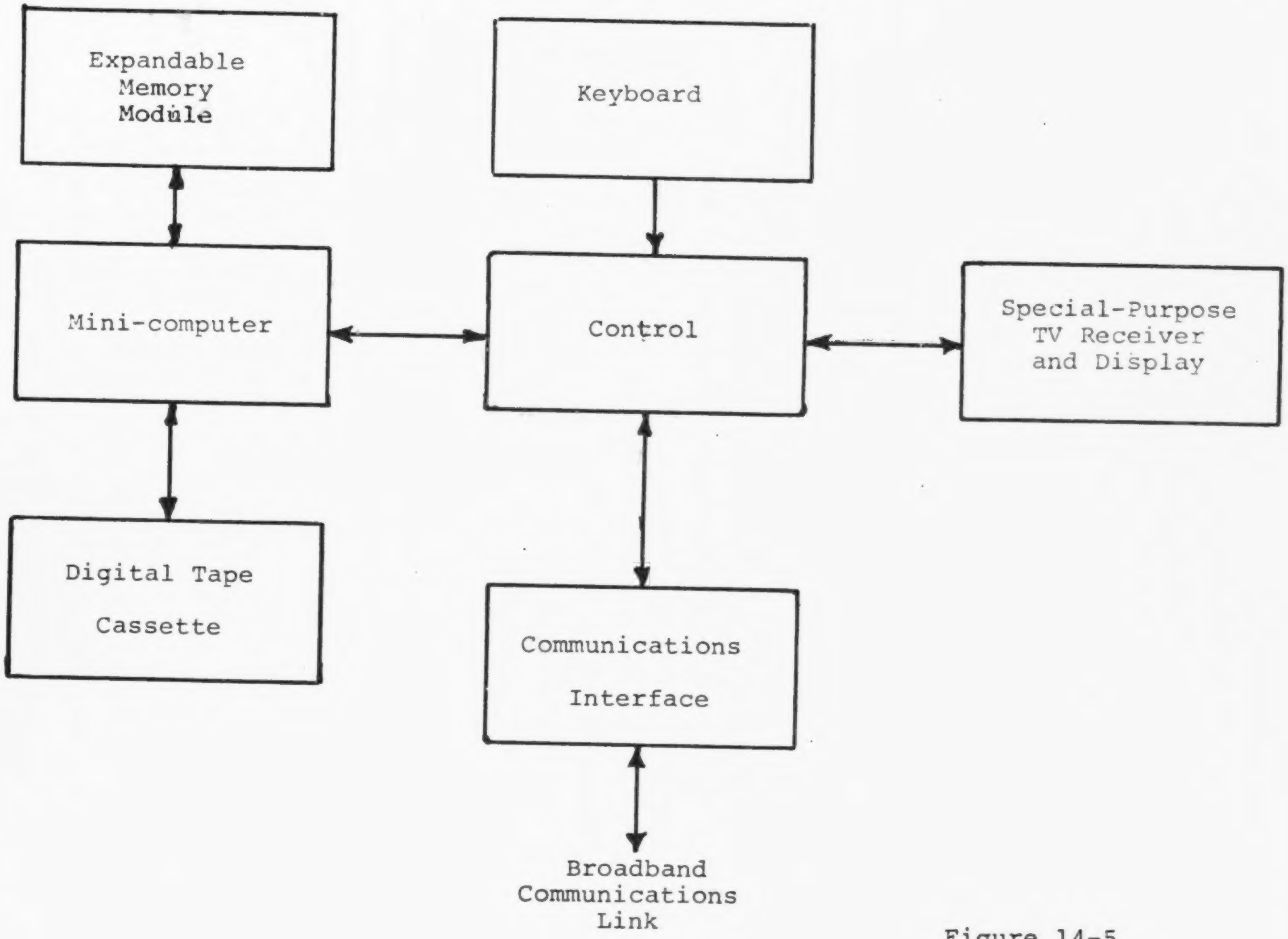

Expandable Memory Module
Keyboard
Mini-computer
Control
Special-Purpose TV Receiver and Display
Digital Tape Cassette
Communications Interface
Broadband Communications Link

Figure 14-5

Projected Interactive Student Terminal

Development of such a low-cost, high-performance user's terminal is one barrier to achieving full interactive capability. The other is the increased complexity of the distribution network.

Consider the system of Figure 14-2. If two-way transmission is required, the CATV cable network first must be capable of accommodating bidirectional communications. This involves one of the techniques described in Chapter 8.

Quite apart from this, however, is the problem of recognizing and controlling the messages from each user. If, for example, 100 students each have terminals and send a request or response to the computer at the school district program origination center, these messages must be "tagged" with the identification of the requestor, queued or accumulated in some programmed sequence, and transmitted to the program center. The responses from the center must be handled in a similar manner.

In effect, the system becomes the equivalent of a point-to-many-points switched-network, but even more complex than a telephone network because broadband signals are transmitted, in at least one direction.

For any sizeable number of user terminals, a computer would be required at the CATV head-end to keep track of and control all communications. Hardware and software costs for this unit might well approximate the costs of the program origination facility itself.

The question of responsibility would pose another problem, with the CATV system operators naturally reluctant to assume this burden without adequate compensation. If the network were owned completely by a school district or municipality, at least this conflict might be obviated. Another solution is for the educational institution automatically to accept this responsibility, providing whatever equipment and manpower is necessary to convert selected CATV channels to the desired two-way mode.

In this case, however, software becomes a huge burden, since the necessary system and traffic control programs are added to the task of generating instructional software, which is formidable in itself.

For these reasons, it is anticipated that the growth of two-way services may be slower than desired by the educational community. Particularly in relation to CATV systems, it is probable that two-way services for business and consumer use, which may generate more sizeable funding, will precede the widespread educational applications.

14-4 Summary

The projected systems touched upon in this chapter can provide only a rudimentary and one-dimensional view of telecommunications' future role in education. Even this limited view is further in doubt since the vital question of which techniques achieve the most desirable educational results has been side-stepped.

It is also obvious that many applications of educational technology will be extremely localized, sometimes complementing and other times substituting for the broader-based, multi-media systems. The home video recorder is an example of this. If the equipment and program costs can be made low enough, the justification for a communications network may decrease and, in many remote areas, may disappear entirely.

Specialized, dedicated local systems (such as an in-school time-sharing computer) will also proliferate, since their relative inefficiencies may be outweighed in many cases by more convenient and flexible control by the using facility.

In spite of these caveats, however, telecommunications has the inherent capability of reaching larger audiences, at lower cost, with a wide variety of educational and instructional material. It represents the best, and perhaps the only, hope

hope of slowing and eventually reversing the educational cost-performance spiral. As such, it warrants the full attention of the educational community and is too vital to be delegated to the telecommunications specialists.

CHAPTER 14 - BIBLIOGRAPHY

1. "Addressed Cable Delivery: Techniques for Rapid, Low-Cost Delivery of Information Products and Services", Information Industry Association submission to the FCC, Docket 18397, Part I, Dec. 19, 1969.

2. Baer, W.S., "Interactive Television: Prospects for Two-Way Services on Cable", Rand Report R-888-MF, Nov. 1971.

3. Jurgen, R.K., "Two-way Applications for Cable Television in the '70's", Institute of Electrical and Electronics Engineers Spectrum, Nov. 1971, p. 39-54.

4. "The Future of Broadband Communications", Electronic Industries Association submission to the FCC, Docket 18397, Part V, Oct. 29, 1969.

TABLE OF ABBREVIATIONS

AC - Alternating Current
ALGOL - Algorithmic Language
AM - Amplitude Modulation
A/V - Audio/Visual
BASIC - Beginner's All-purpose Symbolic Instruction Code
BCN - Broadband Communications Network
bit - Binary Digit
bps - Bits per Second
CAI - Computer Assisted Instruction
CAL - Computer Assisted Learning
CATV - Community Antenna Television
CCTV - Closed Circuit Television
CMI - Computer Managed Instruction
COBOL - Common Business-Oriented Language
ComSat - Communications Satellite Corporation
CPB - Corporation for Public Broadcasting
CRT - Cathode-Ray Tube
DC - Direct Current
DTSS - Dartmouth-Time-Sharing-System
EHF - Extremely High Frequency
EIA - Electronic Industries Association
ER - Educational Radio
ETN - Educational Telephone
ETV - Educational Television
EVR - Electronic Video Recording
FCC - Federal Communications Commission
FM - Frequency Modulation
FORTRAN - Formula Translation
GHz - Gigahertz
HF - High Frequency
Hz - Hertz (cycles per second)
IF - Intermediate Frequency

INTELSAT - International Telecommunications Satellite Consortium
IRTV - Information Retrieval Television
ITFS - Instructional Television Fixed Service
ITU - International Telecommunication Union
ITV - Instructional Television
Kbps - Kilobits per second
KHz - Kilohertz
LF - Low Frequency
MF - Medium Frequency
MM - Millimeter
modem - Modulator/Demodulator
MHz - Megahertz
NAEB - National Association of Educational Broadcasters
NASA - National Aeronautics and Space Agency
NEA - National Education Association
NER - National Educational Radio
NPR - National Public Radio
OCR - Optical Character Reader
PBS - Public Broadcasting Service
RF - Radio Frequency
rpm - Revolutions per Minute
SCA - Subsidiary Communications Authorization
SHF - Super High Frequency
TICCIT - Time-Shared Interactive Computer-Controlled Information Television
TV - Television
UHF - Ultra High Frequency
USACII - United States American Standard Code for Information Interchange
VHF - Very High Frequency
VLF - Very Low Frequency
VTR - Video Tape Recording (or Video Tape Recorder)

GLOSSARY

Amplifier - A device to boost the voltage or current level of an electrical signal.

Amplitude - The magnitude of an electrical voltage or current.

Amplitude modulation - A way of modifying a sine wave signal in order to make it "carry" information. The sine wave, or "carrier", has its amplitude modified in accordance with the information to be transmitted.

Analog data - Data in the form of continuously variable physical quantities.

ASCII - (U.S. American Standard Code for Information Interchange). An eight-level code for data transfer adopted by the American Standards Association to achieve compatibility between data devices (also USASCII).

Attenuation - Decrease in magnitude of current, voltage, or power of a signal in transmission between points.

Audio frequencies - Frequencies that can be heard by the human ear (usually 30 to 20,000 cycles per second).

Bandwidth - The range of frequencies available for signaling. The difference expressed in cycles per second (hertz) between the highest and lowest frequencies of a band.

Baud - Unit of signaling speed. The speed in bauds is the number of discrete conditions or signal events per second. (This is applied only to the actual signals on a communication line.) If each signal event represents only one bit condition, baud is the same as bits per second. When each signal event represents other than one bit, baud does not equal bits per second.

Baudot code - A code for the transmission of data in which five equal-length bits represent one character. This code is used in most DC teletypewriter machines where start and stop elements are added.

Bit - Contraction of "binary digit", the smallest unit of information in a binary system. A bit represents the choice between a mark or space (one or zero) condition.

Bit rate - The speed at which bits are transmitted, usually expressed in bits per second.

Broadband - Communication channel having a bandwidth greater than a voice-grade channel, and therefore capable of higher-speed data transmission.

Cable - Assembly of one or more conductors within an enveloping protective sheath, so constructed as to permit the use of conductors separately or in groups.

Carrier - Continuous frequency capable of being modulated, or impressed with a second (information carrying) signal.

Carrier, communications common - A company which furnishes communications services to the general public, and which is regulated by appropriate local, state, or federal agencies.

Cartridge - An enclosed, single-reel magnetic tape packaging device in which the tape unwinds and rewinds over the same reel in a continuous loop.

Cassette - An enclosed, two-reel magnetic tape packaging device in which the tape winds from reel to reel in either direction.

Channel - A means of one-way transmission.

Channel, analog - A channel on which the information transmitted can take any value between the limits defined by the channel. Most voice channels are analog channels.

Channel, voice-grade - A channel suitable for transmission of speech, digital or analog data, or facsimile, generally with a frequency range of about 300 to 3400 cycles per second.

Character - Letter, figure, number, punctuation or other sign contained in a message.

Circuit - A means of both-way communication between two points comprising associated "go" and "return" channels.

Conditioning - Modifying an electrical curcuit or signal to produce desired characteristics.

Current - The quantity of electricity moving through a medium.

Demodulation - The process of retrieving intelligence (data) from a modulated carrier wave; the reverse of modulation.

Dial-up - The use of a dial or pushbutton telephone to initiate a station-to-station telephone call.

Digital data - Information represented by a code consisting of a sequence of discrete elements.

Digital signal - A discrete or discontinuous signal; one whose various states are discrete intervals apart.

Duplex transmission - Simultaneous two-way independent transmission in both directions.

Facsimile (FAX) - a system for the transmission of images. The image is scanned at the transmitter, reconstructed at the receiving station, and duplicated on some form of paper.

Field - One-half of a complete TV picture (or frame) interval containing all of the odd or even scanning lines of the picture.

Field Frequency - The rate at which a complete field is scanned, nominally 60 times a second.

Film Chain - Film (or slide) projectors optically linked to a video camera so that the photographic images are converted into video signals.

Filter - A network designed to transmit currents of frequencies within one or more frequency bands and to attenuate currents of other frequencies.

Frame - One complete TV picture consisting of two fields of interlaced scanning lines.

Frame Frequency - The rate at which a complete frame is scanned, nominally 30 frames per second.

Frequency - A measure of the rate of alternation in the flow of current. Expressed in cycles per second or Hertz.

Frequency-division multiplex - A multiplex system in which the available transmission frequency range is divided into narrower bands, each used for a separate channel.

Frequency modulation - A way of modifying a sine wave signal to make it "carry" information. The sine wave or "carrier" has its frequency modified in accordance with the information to be transmitted.

Half-duplex Transmission - A circuit designed for transmission in either direction but not both directions simultaneously.

Hertz (Hz) - A measure of frequency or bandwidth. The same as cycles per second.

Leased facility - A facility reserved for sole use of a single leasing customer.

Mark - Presence of signal. In telegraph communications a mark represents the closed condition or current flowing. A mark impulse is equivalent to a binary 1.

Message switching - The technique of receiving a message, storing it until the proper outgoing line is available, and then retransmitting.

Microwave - Any electromagnetic wave in the radio-frequency spectrum above 1000 megacycles per second.

Modem (Data set) - a device which performs the modulation/demodulation and control functions necessary to provide compatibility between digital data and analog communications facilities.

Modulation - The process by which some characteristic of one wave is varied in accordance with another wave or signal.

Multiplexing - The division of a transmission facility into two or more channels, each of which is used to constitute a distinct signal.

Noise - Random electrical signals, introduced by circuit components or natural disturbances, which tend to degrade the performance of a communications channel.

On-line computer system - One in which the input data enter the computer directly from their point of origin and output data are transmitted directly to where they are used.

Orthicon (image) - A camera tube in which the optical image falls on a photoemissive cathode which emits electrons that are focused on a target at high velocity. The target is scanned from the rear by a low-velocity electron beam.

Parallel transmission - Simultaneous transmission of the bits making up a character.

Parity check - Addition of noninformation bits to data, making the number of ones in a grouping of bits either always even or always odd. This permits detection of bit groupings that contain single errors.

Power - Electrically, the product of voltage and current.

Private line - Denotes the channel and channel equipment furnished to a customer as a unit for his exclusive use, without interexchange switching arrangements.

Real time - A real-time computer system may be defined as one that controls an environment by receiving data, processing them, and returning the results sufficiently quickly to affect the functioning of the environment at that time.

Resistance - In electrical terms, a measure of how much voltage is necessary to force current through a medium.

Resolution - The amount of resolvable detail in a picture.

Scanning - The process of breaking down an image into a series of elements or groups of elements representing light values and transmitting this information in time sequence.

Serial transmission - A system wherein the bits of a character occur serially in time. Implies only a single transmission channel

Simplex transmission - A circuit permitting transmission in one specific direction only.

Space - An impulse which causes current to flow in a direction opposite to that for a mark impulse. A space impulse is equivalent to a binary 0.

Spectrum - A continuous range of frequencies, usually wide in extent, within which waves have some specific common characteristic.

Teletype - Trademark of Teletype Corporation, usually referring to a series of different types of teleprinter equipment utilized for communications systems.

Telex service - A dial-up telegraph service enabling its subscribers to communicate directly among themselves by means of circuits of the public telegraph network.

Terminal - Any device capable of sending and/or receiving information over a communication channel.

Time-division multiplex - A system in which a number of distinct signals are connected intermittently to a common channel.

Touch-tone - AT&T term for pushbutton dialing.

Video - The bandwidth and spectrum position of the signal which results from television scanning and which is used to reproduce a picture.

Video Band - The frequency band utilized to transmit a composite video signal.

Voice-frequency - Any frequency within that part of the audio-frequency range essential for the transmission of speech of commercical quality, i.e., 300-3400 Hz.

Voltage - The electrical equivalent of pressure or force available to move current through a conducting medium.

Word - In computing, a sequence of bits or characters treated as a unit and capable of being stored in one computer location.